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ELECTRIC WIRING AND LIGHTING

KNOX - SHAAD

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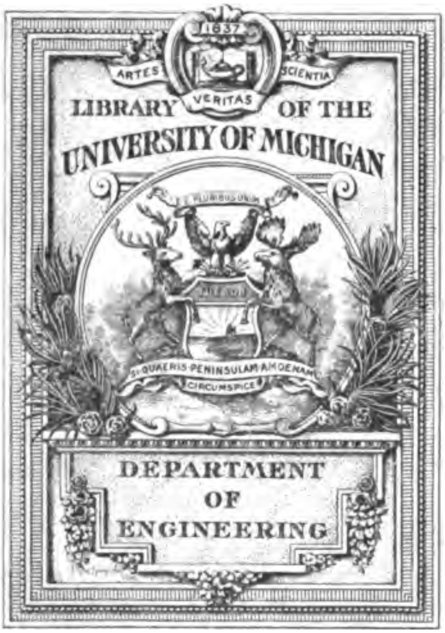

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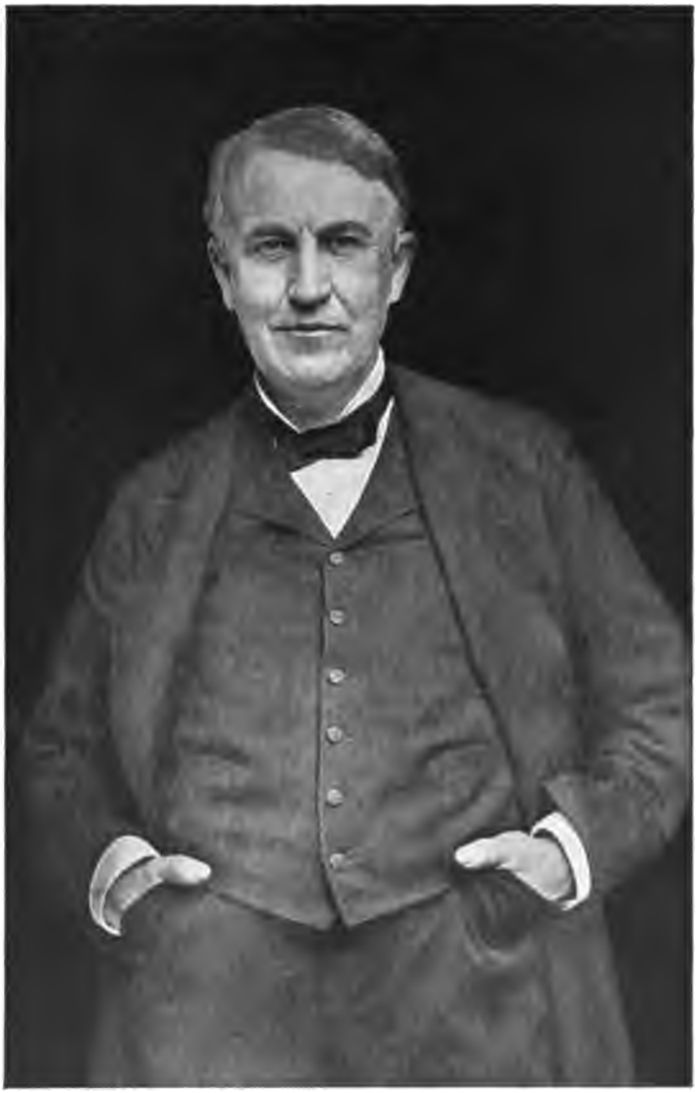

THOMAS A. EDISON,
Inventor of Telegraphic Appliances, Phonograph,
Incandescent Lamp, and Many Other Electrical Devices.

Electric Wiring and Lighting

A Working Handbook of
APPROVED MODERN METHODS OF LIGHTING BY ELECTRICITY, AND OF INSTALLING CONDUCTORS FOR THE TRANSMISSION AND UTILIZATION OF ELECTRICITY FOR POWER, LIGHTING, HEATING, AND OTHER USES

PART I—ELECTRIC WIRING

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Consulting Electrical Engineer

PART II—ELECTRIC LIGHTING

By GEORGE C. SHAAD, E. E.
Associate Professor of Electrical Engineering
Massachusetts Institute of Technology

ILLUSTRATED

CHICAGO
AMERICAN SCHOOL OF CORRESPONDENCE
1909

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Foreword

IN recent years, such marvelous advances have been made in the engineering and scientific fields, and so rapid has been the evolution of mechanical and constructive processes and methods, that a distinct need has been created for a series of *practical working guides*, of convenient size and low cost, embodying the accumulated results of experience and the most approved modern practice along a great variety of lines. To fill this acknowledged need, is the special purpose of the series of handbooks to which this volume belongs.

¶ In the preparation of this series, it has been the aim of the publishers to lay special stress on the *practical* side of each subject, as distinguished from mere theoretical or academic discussion. Each volume is written by a well-known expert of acknowledged authority in his special line, and is based on a most careful study of practical needs and up-to-date methods as developed under the conditions of actual practice in the field, the shop, the mill, the power house, the drafting room, the engine room, etc.

¶ These volumes are especially adapted for purposes of self-instruction and home study. The utmost care has been used to bring the treatment of each subject within the range of the com-

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mon understanding, so that the work will appeal not only to the technically trained expert, but also to the beginner and the self-taught practical man who wishes to keep abreast of modern progress. The language is simple and clear; heavy technical terms and the formulæ of the higher mathematics have been avoided, yet without sacrificing any of the requirements of practical instruction; the arrangement of matter is such as to carry the reader along by easy steps to complete mastery of each subject; frequent examples for practice are given, to enable the reader to test his knowledge and make it a permanent possession; and the illustrations are selected with the greatest care to supplement and make clear the references in the text.

❡ The method adopted in the preparation of these volumes is that which the American School of Correspondence has developed and employed so successfully for many years. It is not an experiment, but has stood the severest of all tests—that of practical use—which has demonstrated it to be the best method yet devised for the education of the busy working man.

❡ For purposes of ready reference and timely information when needed, it is believed that this series of handbooks will be found to meet every requirement.

Table of Contents

PART I—ELECTRIC WIRING

METHODS OF WIRING FOR DIRECT AND ALTERNATING CURRENT Page 1

Wires Run in Conduits—Metal Conduit, Rigid and Flexible—Armored Conduit—Armored Cable—Outlet Boxes, Plates, and Bushings—Wires Run in Moulding—Sizes of Moulding—Rosettes and Tapping Devices—Knob and Tube Wiring—Fibrous Tubing—Wires Exposed on Insulators—Two-Wire and Three-Wire Systems—Calculation of Sizes of Conductors—Formulæ for Calculating Current, Length of Circuit, and Loss in Circuit—Planning an Installation—Choice of Wiring System—Location of Outlets—Chases for Feeders and Mains—Location of Cut-Out Cabinets and Distributing Centers—Layout of Branch Circuits—Number of Outlets and Lights—Conductors Concealed under Floors—Testing of Circuits and Fixtures — Alternating-Current Circuits — Self-Induction — Skin Effect — Mutual Induction — Line Capacity — Drop in A. C. Lines — Single-Phase and Polyphase Circuits—Wiring an Office Building—Overhead Linework—Selecting and Placing Poles—Guying and Bracing—Cross-Arms—Turns in Lines—Pins—Insulators—Service Mains—Pole Wiring—Transformers—Lightning Arresters—Underground Linework—Iron Pipe—Vitrified Conduit—Fibre Conduit—Drawing-in Cables—Manholes

ELECTRIC BELL WIRING . . . . Page 89

Size of Wire—Methods of Running Wires—Joints—Soldering—Bell-Push—Batteries—Bells—Circuits—Burglar and Fire Alarms

PART II—ELECTRIC LIGHTING

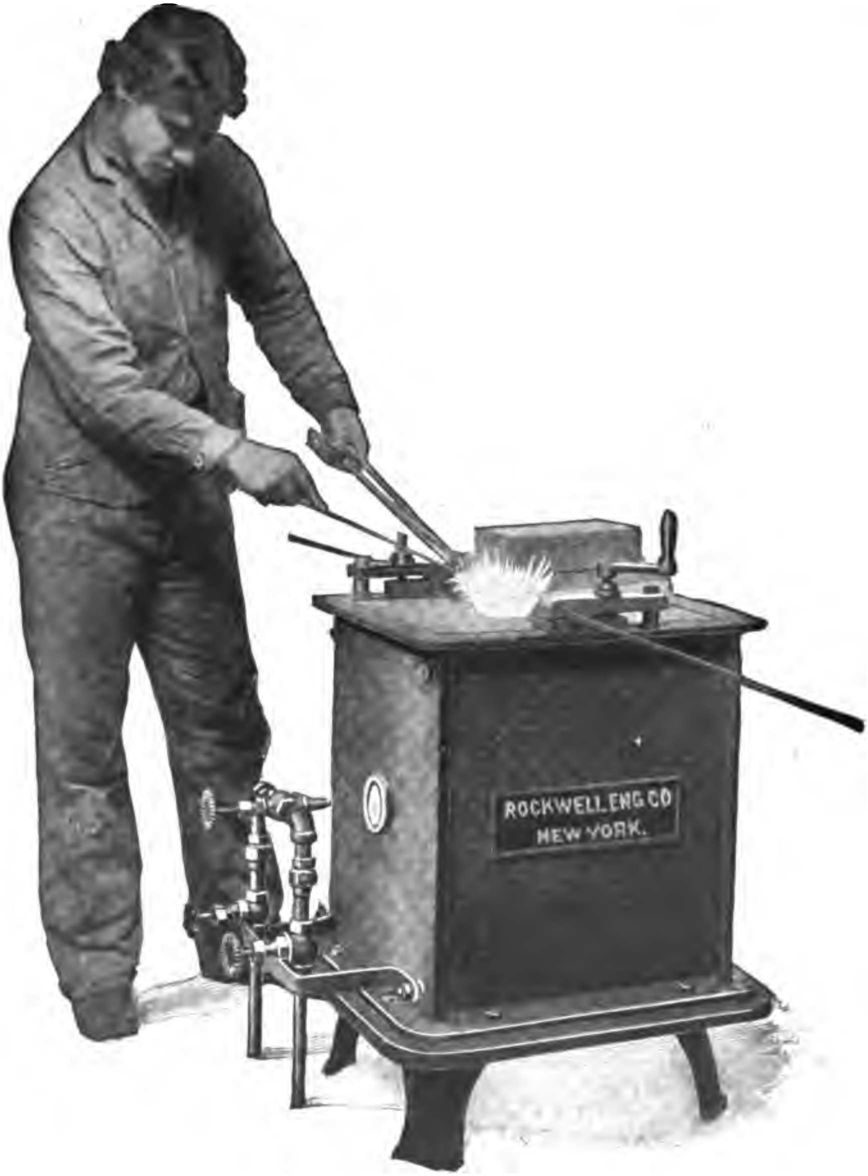
LAMPS AND LIGHTING CIRCUITS . . . . Page 3

Historical Development of Electric Lighting—Incandescent Lamp—Manufacture of Filament—Voltage and Candle-Power—Efficiency—Life Term of a Lamp—Smashing Point—Distribution of Light—Arc Lamps (Shunt, Series, and Differential)—Rod and Carbon Feed—Double-Carbon Lamps—Open and Enclosed Arcs—Use of Alternating Current and Constant-Potential Direct Current—Rating and Efficiency of Arc Lamps—Nernst Lamp—Osmium Lamp—Bremer Arc Lamp—Hewitt Mercury-Vapor Lamp—Systems of Power Distribution (Series, Multiple-Series, Series-Multiple, Multiple or Parallel)—Regulation of Voltage Drop

LIGHTING OF BUILDINGS AND STREETS, PHOTOMETRY, ETC. . Page 40

Unit of Illumination—Candle-Foot—Useful and Scenic Illumination—Intrinsic Brightness—Regular Reflection—Diffusion—Lighting of Residences; of Public Halls, Offices, etc.—Lighting of Streets—Shades and Reflectors—Photometry—Light Standards—The English Candle—The German Candle—The Hefner or Amyl-Acetate Lamp—Working Standards—Shop Lighting—Distribution of Sunlight—Welsbach Burner—Adjustable Fixtures

INDEX . . . . Page 83



COPPER WIRE BRAZING FURNACE.
Rockwell Engineering Co.

ELECTRIC WIRING

METHODS OF WIRING

The different methods of wiring which are now approved by the National Board of Fire Underwriters, may be classified under four general heads, as follows:

1. Wires Run Concealed in Conduits.
2. Wires Run in Moulding.
3. Concealed Knob and Tube Wiring.
4. Wires Run Exposed on Insulators.

WIRES RUN CONCEALED IN CONDUITS

Under this general head, will be included the following:

(*a*) Wires run in rigid conduits.
(*b*) Wires run in flexible metal conduits.
(*c*) Armored cable.

Wires Run in Rigid Conduit. The form of rigid metal conduit now used almost exclusively, consists of plain iron gaspipe the interior surface of which has been prepared by removing the scale and by removing the irregularities, and which is then coated with flexible enamel. The outside of the pipe is given a thin coat of enamel in some cases, and, in other cases, is galvanized. Fig. 1 shows one make of enameled (unlined) conduit.

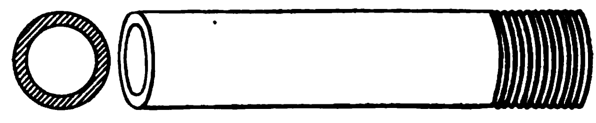


Fig. 1. Rigid Enameled Conduit, Unlined.
Courtesy of American Conduit Mfg. Co., Pittsburg, Pa.

Another form of rigid conduit is that known as the *armored conduit,* which consists of iron pipe with an interior lining of paper impregnated with asphaltum or similar compound. This latter form of conduit is now rapidly going out of use, owing to the unlined pipe being cheaper and easier to install, and owing also to improved methods of protecting the iron pipe from corrosion, and to the introduction of additional braid on the conductors, which partly compensates for the pipe being unlined. The introduction of improved devices—such as outlet insulators, for protecting the conductors from the sharp edges of the pipe, at outlets, cut-out cabinets, etc.—also decreases the necessity of the additional protection afforded by the interior paper lining.

Rigid conduits are made in gaspipe sizes, from one-half inch to three inches in diameter. The following table gives the various data relating to rigid, enameled (unlined) conduit:

TABLE I
Rigid, Enameled Conduit—Sizes, Dimensions, Etc.

Standard Pipe Size	Thickness	Nominal Weight per 100 Feet	Number of Threads per Inch of Screw	Actual Outside Diameter. Inches	Nominal Inside Diameter. Inches
½	.109	84	14	.84	.62
¾	.113	112	14	1.05	.82
1	.134	167	11½	1.31	1.04
1¼	.140	224	11½	1.66	1.38
1½	.145	268	11½	1.90	1.61
2	.154	361	11½	2.37	2.06
2½	.204	574	8	2.87	2.46
3	.217	754	8	3.50	3.06

Tables II, III, and IV give the various sizes of conductors that may be installed in these conduits. Caution must be exercised in

TABLE II
Single Wire in Conduit

Size Wire, B. & S. G.	Loricated Conduit, Unlined; D. B. Wire
No. 14-4	½ inch
" 2	¾ "
" 1	¾ "
" 0	¾ inch or 1 "
" 00	1 "
" 000	1 "
" 0000	1 "
250,000 C. M.	1¼ "
300,000 C. M.	1¼ "
350,000 C. M.	1¼ "
400,000 C. M.	1¼ " or 1½ "
450,000 C. M.	1½ "
500,000 C. M.	1½ "
600,000 C. M.	1½ " or 2 "
700,000 C. M.	2 "
800,000 C. M.	2 "
900,000 C. M.	2 "
1,000,000 C. M.	2 " or 2½ "
1,500,000 C. M.	2½ "
1,700,000 C. M.	3 "
2,000,000 C. M.	3 "

TABLE III

Two Wires in One Conduit

Size Wire, B. & S. G.	Loricated Conduit, Unlined; D. B. Wire
No. 14	½ inch.
" 12	½ inch or ¾ "
" 10	¾ "
" 8	1 "
" 6	1 "
" 5	1 " or 1¼ "
" 4	1¼ "
" 3	1¼ "
" 2	1¼ " or 1½ "
" 1	1½ "
" 0	1½ "
" 00	1½ " or 2 "
" 000	2 "
" 0000	2 "
250,000 C. M.	2 " or 2½ "
300,000 C. M.	2½ "
350,000 C. M.	2½ "
400,000 C. M.	2½ " or 3 "
450,000 C. M.	3 "
500,000 C. M.	3 "
600,000 C. M.	3 "
700,000 C. M.	3 "

TABLE IV

Three Wires in One Conduit

Size Wire, B. & S. G.		Loricated Tube, Unlined; D. B. Wire
Outside	Center	
No. 14	No. 12	¾ inch
" 12	" 10	¾ "
" 10	" 8	1 "
" 8	" 6	1 "
" 6	" 4	1¼ "
" 5	" 2	1¼ "
" 4	" 1	1¼ inch or 1½ "
" 3	" 0	1½ "
" 2	" 2/0	1½ " or 2 "
" 1	" 3/0	2 "
" 0	" 4/0	2 "
" 2/0	250 M.	2 " or 2½ "
" 3/0	300 M.	2½ "
" 4/0	400 M.	2½ "
250 M.	450 M.	2½ " or 3 "
250 M.	500 M.	3 "
300 M.	600 M.	3 "
350 M.	700 M.	3 "
400 M.	800 M.	3 "
450 M.	900 M.	3 "

using these tables, for the reason that the sizes of conductors which may be safely installed in any run of conduit depend, of course, upon the length of and the number of bends in the run. The tables are based on average conditions where the run does not exceed 90 to 100 feet, without more than three or four bends, in the case of the smaller sizes of wires for a given size of conduit; and where the run does not exceed 40 to 50 feet, with not more than one or two bends, in the case of the larger sizes of wires, for the same sizes of conduit.

Unlined conduit can be bent without injury to the conduit, if the conduit is properly made and if proper means are used in making the bends. Care should be exercised to avoid flattening the tube as a result of making the bend over a sharp curve or angle.

In installing iron conduits, the conduits should cross sleepers or beams at right angles, so as to reduce the amount of cutting of the beams or sleepers to a minimum.

Where a number of conduits originate at a center of distribution, they should be run at right angles for a distance of two or three feet from the cut-out box, in order to obtain a symmetrical and workmanlike arrangement of the conduits, and so as to have them enter the cabinet in a neat manner. While it is usual to use red or white lead at the joints of conduits in order to make them water-tight, this is frequently unnecessary in the case of enameled conduit, as there is often sufficient enamel on the thread to make a water-tight joint.

When iron conduits are installed in ash concrete, in Keene cement, or, in general, where they are subject in any way to corrosive action, they should be coated with asphaltum or other similar protective paint to prevent such action.

While the cost of circuit work run in iron conduits is usually greater than any other method of wiring, it is the most permanent and durable, and is strongly recommended where the first cost is not the sole consideration. This method of wiring should always be used in fireproof buildings, and also in the better class of frame buildings. It is also to be recommended for exposed work where the work is liable to disturbance or mechanical damage.

Wires Run in Flexible Metal Conduit. This form of conduit, shown in Fig. 2, is described by the manufacturers as a conduit composed of "concave and convex metal strips wound spirally upon each other in such a manner as to interlock several concave surfaces and present their convex surfaces, both exterior and interior, thereby securing a smooth and comparatively frictionless surface inside and out."

The field for the use of this form of conduit is rapidly increasing. Owing to its flexibility, conduit of this type can be used in numerous cases where the rigid conduit could not possibly be employed. Its use is to be recommended above all the other forms of wiring, except that installed in rigid conduits. For new fireproof buildings, it is not so durable as the rigid conduit, because not so water-tight; and it is very difficult, if not impossible, to obtain as workmanlike a conduit system with the flexible as with the rigid type of conduit. For completed or old frame buildings, however, the use of the flexible conduit is superior to all other forms of wiring.

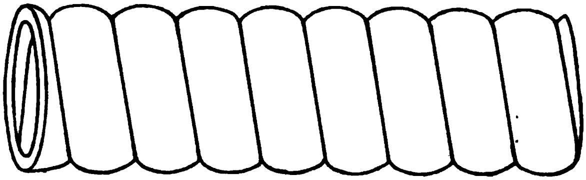


Fig. 2. Flexible Steel Conduit.
Courtesy of Sterling Electric Co., Troy, N. Y.

Table V gives the inside diameter of various sizes of flexible conduit, and the lengths of standard coils. inside diameter of this conduit is the same as that of the rigid conduit; and the table given for the maximum sizes of conductors which may be installed in the various sizes of conduits, may be used also for flexible steel conduits, except that a little more margin should be allowed for flexible steel conduits than for the rigid conduits, as the stiffness of the latter makes it possible to pull in slightly larger sized conductors.

TABLE V
Greenfield Flexible Steel Conduit

Inside Diameter	Approximate Feet in Coil
$\frac{5}{16}$ inch	200
$\frac{3}{8}$ "	200
$\frac{1}{2}$ "	100
$\frac{3}{4}$ "	50
1 "	50
$1\frac{1}{4}$ inches	50
$1\frac{1}{2}$ "	50
2 "	Random Lengths
$2\frac{1}{2}$ "	" "
3 "	" "

This conduit should, of course, be first installed without the conductors, in the same manner as the rigid conduit. Owing to the flexibility of this conduit, however, it is absolutely essential to fasten it securely at all elbows, bends, or offsets; for, if this is not done, considerable difficulty will be experienced in drawing the conductors in the conduit.

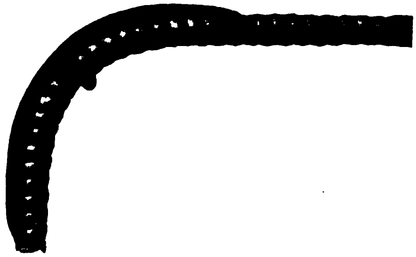


Fig. 3. Use of Elbow Clamp for Fastening Flexible Conduit in Place.

The rules governing the installation of this conduit are the same as those covering rigid conduits. Double-braided conductors are required, and the conduit should be grounded as required by the *Code Rules.* As already stated, the conduit should be securely fastened (in not less than three places) at all elbows; or else the special elbow clamp made for this purpose, shown in Fig. 3, should be used.

In order to cut flexible steel conduit properly, a fine hack saw should be employed. Outlet-boxes are required at all outlets, as well as bushing and wires to rigid conduit. Fig. 4 shows a coil of flexible steel conduit. Figs. 5, 6, and 7 show, respectively, an outlet box and cover, outlet plate, and bushing used for this conduit.

Fig. 4. A 100-Foot Coil of Flexible Steel Conduit. *Courtesy of Sprague Electric Co., New York, N.Y.*

Armored Cable. There are many cases where it is impossible to install a conduit system. In such cases, probbably the next best results may be obtained by the use of *steel armored cable.* The rules governing the installation of armored cable are given in the *National Electric Code,* under Section 24-A, and Section 48; also in 24–S. This cable is shown in Fig. 8.

Steel armored cable is made by winding formed steel strips over the insulated conductors. The steel strips are similar to those used for the steel conduit. Care is taken in forming the cable, to avoid crushing or abraiding the insulation on the conductors as the steel strips are fed and formed over the same. In the process of manufacture, the spools of steel ribbon are of irregular length, and when a spool is empty, the machine is stopped, and the ribbon is started on the next spool, the process being continued. There is no reason why the conduit cables could not be made of any length; but their actual lengths as made are determined by convenience in handling. Armored

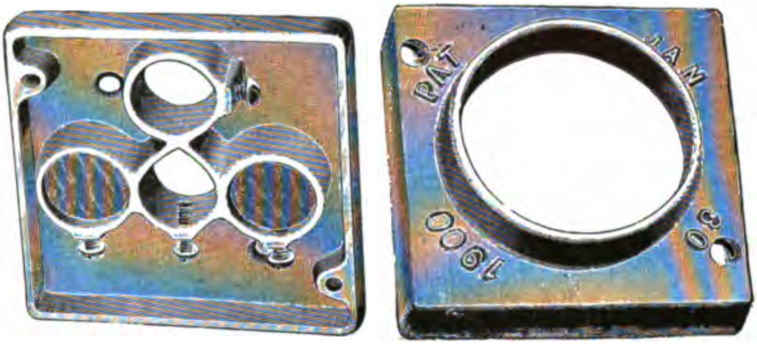


Fig. 5. Outlet Box for Flexible Steel Conduit.

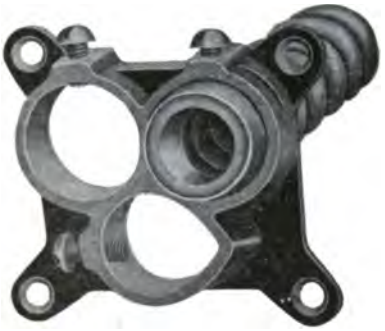


Fig. 6. Outlet Plate for Flexible Steel Conduit.

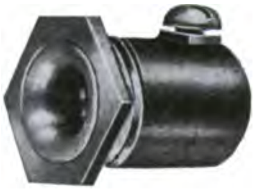


Fig. 7. Outlet Bushing.
Courtesy of Sprague Electric Co., New York, N. Y.

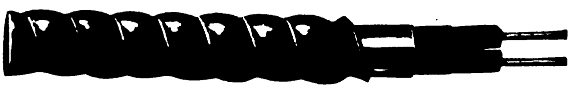


Fig. 8. Flexible Armored Cable. Twin Conductors.
Courtesy of Sprague Electric Co., New York, N. Y.

cable is made in *single conductors* from No. 1 to No. 10 B. & S. G.; in *twin conductors,* from No. 6 to No. 14 B. & S. G.; and *three-conductor* cable, from No. 10 to No. 14 B. & S. G. Table VI gives various data relating to armored conductors:

TABLE VI

Armored Conductors—Types, Dimensions, Etc.

Size B. & S. Gauge	Type and Number of Conductors	Outside Diameter (Inches)
No. 14	BX twin conductor	.63
" 12	" " "	.685
" 10	" " "	.725
" 8	" " "	.875
" 6	" " "	1.3125
" 14	BM twin conductor (for marine work—ship wiring)	.725
" 12	" " "	.725
" 10	" " "	.73
" 14	BX3 three conductor	.71
" 12	" " "	.725
" 10	" " "	.73
" 14	BXL twin conductor, leaded	.725
" 12	" " " "	.725
" 10	" " " "	.87
" 14	BXL3 three conductor, leaded	.90
" 12	" " " "	.90
" 10	" " " "	.94
" 10	Type D single conductor, stranded	.550
" 8	" " " " "	.550
" 6	" " " " "	.575
" 4	" " " " "	.700
" 2	" " " " "	.900
" 1	" " " " "	.965
" 10	Type DL single conductor, stranded, leaded	.625
" 8	" " " " " "	.710
" 6	" " " " " "	.700
" 4	" " " " " "	.760
" 2	" " " " " "	.920
" 1	" " " " " "	.910
	Steel Armored Flexible Cord.	
" 18	Type E twin conductor	.40
" 16	" " " "	.40
" 14	" " " "	.47
" 18	Type EM twin conductor, re-inforced	.575
" 16	" " " " "	.585
" 14	" " " " "	.595

In Table VI, Types D (single), BX (twin), and BX3 (3 conductors) are armored cable adapted for ordinary indoor work. Type BM (twin conductors) is adapted for marine wiring. Types DL (single), BXL (twin), and BXL 3 (3 conductors) have the conductors lead-encased, with the steel armor outside, and are especially adapted for damp places, such as breweries, stables, and similar places.

Type E is used for flexible-cord pendants, and is suitable for factories, mills, show windows, and other similar places. Type EM is the same as Type E; but the flexible cord is reinforced, and is suitable for marine work, for use in damp places, and in all cases where it will be subject to very rough handling.

While this form of wiring has not the advantage of the conduit system—namely, that the wires can be withdrawn and new wires inserted without disturbing the building in any way whatever—yet it has many of the advantages of the flexible steel conduit, and it has some additional advantages of its own. For example, in a building already erected, this cable can be fished between the floors and in the partition walls, where it would be impossible to install either rigid conduit or flexible steel conduit without disturbing the floors or walls to an extent that would be objectionable.

Armored conductors should be continuous from outlet to outlet, without being spliced and installed on the loop system. Outlet boxes should be installed at all outlets, although, where this is impossible, outlet plates may be used under certain conditions. Clamps should be provided at all outlets, switch-boxes, junction-boxes, etc., to hold the cable in place, and also to serve as a means of grounding the steel sheathing.

Armored cable is less expensive than the rigid conduit or the flexible steel conduit, but more expensive than cleat wiring or knob and tube wiring, and is strongly recommended in preference to the latter.

WIRES RUN IN MOULDING

Moulding is very extensively used for electric circuit work, in extending circuits in buildings which have already been wired, and also in wiring buildings which were not provided with electric circuit work at the time of their erection. The reason for the popularity of moulding is that it furnishes a convenient and fairly good-looking runway for the wires, and protects them from mechanical injury.

It seems almost unwise to place conductors carrying electric current, in wood casing; but this method is still permitted by the *National Electric Code,* although it is not allowed in damp places or in places where there is liability to dampness, such as on brick walls, in cellars, etc.

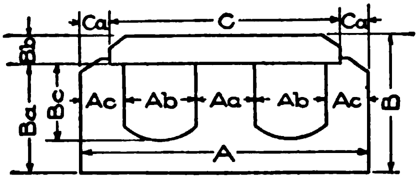


Fig. 9. Two-Wire Wood Moulding.

The dangers from the use of moulding are that if the wood becomes soaked with water, there will be a liability to leakage of current between the conductors run in the grooves of the moulding, and to fire being thereby started, which may not be immediately discovered. Furthermore, if the conductors are overloaded, and consequently overheated, the wood is likely to become charred and finally ignited. Moreover, the moulding itself is always a temptation as affording a good "round strip" in which to drive nails, hooks, etc. However, the convenience and popularity of moulding cannot be denied; and until some better substitute is found, or until its use is forbidden by the *Rules,* it will continue to be used to a very great extent for running circuits outside of the walls and on the ceilings of existing buildings. Figs. 9, 10, 11, and 12 show two- and three-wire moulding respectively; and Table VII gives complete data as to sizes of the moulding required for various sizes of conductors.

While the *Rules* recommend the use of hardwood moulding, as a matter of fact probably 90 per cent of the moulding used is of whitewood or other similar cheap, soft wood. Georgia pine or oak ordinarily costs about twice as much as the soft wood. In designing moulding work, if appearance is of importance, the moulding circuits should be laid out so as to afford a symmetrical and complete design. For

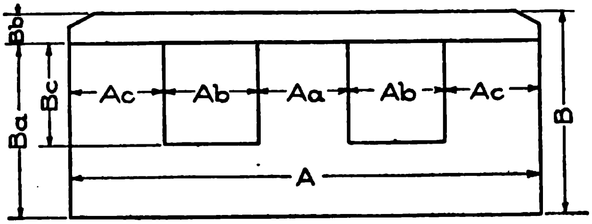


Fig. 10. Two-Wire Wood Moulding.

example, if an outlet is to be located in the center of the ceiling, the moulding should be continued from wall to wall, the portion beyond the outlet, of course, having no conductors inside of the moulding. If four outlets are to be placed on the ceiling, the rectangle of moulding should be completed on the fourth side, although, of course, no conductors need be placed in this portion of the moulding. Doing this increases the cost but little and adds greatly to the appearance.

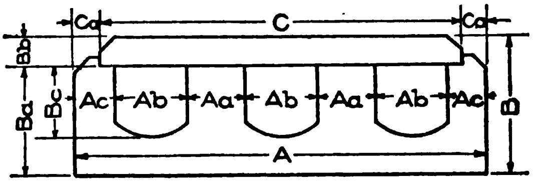


Fig. 11. Three-Wire Wood Moulding.

Moulding is frequently used in combination with other methods of wiring, including armored cable, flexible steel tubing, and fibrous tubing. In many instances, it is possible to fish tubing between beams or studs running in a certain direction; but when the conductors are to run in another direction or at right angles to the beams or studs, exposed work is necessary. In such cases, a junction-box or outlet-box must be placed at the point of connection between the moulding and the armored cable or steel tubing.

Where circuits are run in moulding, and pass through the floor, additional protection must be provided, as required by the *Code Rules*, to protect the moulding. As a rule, it is better to use conduit for all portions of moulding within six feet of the floor, so as to avoid the possibility of injury to the circuits. Where a combination of iron conduit or flexible steel tubing is used with moulding, it is well to use double-braided conductors throughout, because, although only single-

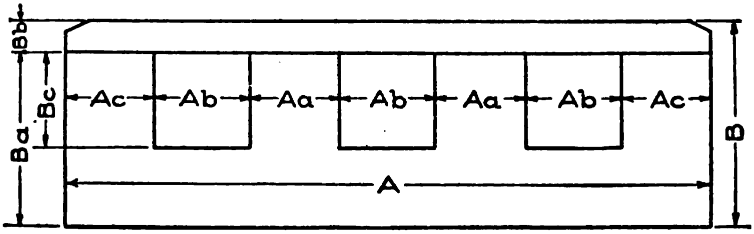


Fig. 12. Three-Wire Wood Moulding.

TABLE VII

Sizes of Mouldings Required for Various Sizes of Conductors

FIG. No.	TYPE OF MOULDING	NUMBER OF WIRES	MAXIMUM SIZE OF WIRE B AND S. GAUGE		DIMENSIONS IN INCHES									
			SOLID	STRANDED	A	Aa	Ab	Ac	B	Ba	Bb	Bc	C	Ca
9	A-2	2	12	14	1 1/2	1/2	1/4	1/4	27/32	5/8	7/32	1/4	1 1/8	3/16
9	A-4	2	8	10	1 11/16	1/2	5/16	9/32	29/32	11/16	7/32	5/16	1 5/16	3/16
9	A-6	2	4	5	2	1/2	7/16	5/16	1 1/16	13/16	1/4	7/16	1 9/16	7/32
9	A-8	2	1	2	2 3/8	1/2	9/16	3/8	1 3/16	15/16	1/4	9/16	1 13/16	9/32
9	A-9	2	–	3/0	3	5/8	3/4	7/16	1 13/32	1 1/8	9/32	3/4	2 7/16	9/32
10	A-10	2	–	250,000 C.M.	3 15/16	11/16	7/8	3/4	1 11/16	1 3/8	5/16	7/8	—	—
10	A-11	2	–	400,000 C.M.	4 7/8	15/16	1	31/32	2 3/16	1 7/8	5/16	1	—	—
11	B-2	3	12	14	2 3/16	7/16	1/4	9/32	27/32	5/8	7/32	1/4	1 13/16	3/16
11	B-4	3	8	10	2 1/2	15/32	5/16	5/16	29/32	11/16	7/32	5/16	2 1/8	3/16
11	B-6	3	4	5	2 7/8	13/32	7/16	3/8	1 1/16	13/16	1/4	7/16	2 3/8	1/4
11	B-8	3	1	2	3 5/8	19/32	9/16	3/8	1 3/16	15/16	1/4	9/16	3 1/16	9/32
11	B-9	3	–	3/0	4 5/16	9/16	3/4	15/32	1 13/32	1 1/8	9/32	3/4	3 3/4	9/32
12	B-10	3	–	250,000 C.M.	5 1/2	23/32	7/8	23/32	1 11/16	1 3/8	5/16	7/8	—	—
12	B-11	3	–	400,000 C.M.	6 3/4	15/16	1	15/16	2 3/16	1 7/8	5/16	1	—	—

braided conductors are required with moulding, double-braided conductors are required with unlined conduit, and if double-braided conductors were not used throughout, it would be necessary to make a joint at the outlet-box where the moulding stopped and the conduit work commenced. Where the conductors pass through floors, in moulding work, and where iron conduit is used, the inspection authorities, in order to protect the wire, usually require that a fibrous tubing be used as additional protection for the conductors inside of the iron pipe, although, if double-braided wire is used, this will not usually be required. Fig. 13 shows a fuseless cord rosette for use with moulding work. Fig. 14 shows a device for making a *tap* in moulding wiring.

Moulding work, under ordinary conditions, costs about one-half as much as circuit run in rigid conduit, and about 75 per cent, under ordinary conditions, of the cost of armored cable. Where the latter method of wiring or the conduit system can be employed, one or the other of these two methods should be used in preference to moulding, as the work is not only more substantial, but also safer. Various forms of metal moulding have been introduced, but up to the present time have not met with the success which they deserve.

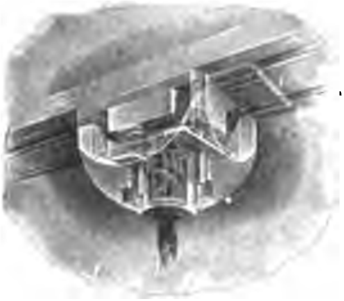


Fig. 13 Fuseless Cord Rosette.
Courtesy of Crouse-Hinds Co., Syracuse, N. Y.

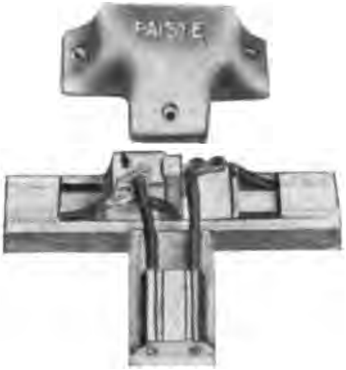


Fig. 14. Device for Making "Tap" in Moulding.
Courtesy of H. T. Paiste Co., Philadelphia, Pa.

CONCEALED KNOB AND TUBE WIRING

This method of wiring is still allowed by the *National Electric Code*, although many vigorous attempts have been made to have it abolished. Each of these attempts has met with the strongest opposition from contractors and central stations, particularly in small towns and villages, the argument for this method being, that it is the cheapest method of wiring, and that if it were forbidden, many places which are wired according to this method would not be wired at all, and the use of electricity would therefore be much restricted, if not entirely done away with, in such communities. This argument, however, is only a temporary makeshift obstruction in the way of inevitable progress, and in a few years, undoubtedly, the concealed knob and tube method will be forbidden by the *National Electric Code*.

The cost of wiring according to this method is about one-third of the cost of circuits run in rigid conduit, and about one-half of the cost of circuits run in armored cable. The latter method of wiring is rapidly replacing knob and tube wiring, and justly so, wherever the additional price for the latter method of wiring can be obtained. As the name indicates, this method of wiring employs *porcelain knobs and tubes*, the circuit work being run *concealed* between the floor beams and studs of a frame building. The knobs are used when the circuits run parallel to the floor beams; and the porcelain tubes are used when the circuits are run at right angles to the floor beams.

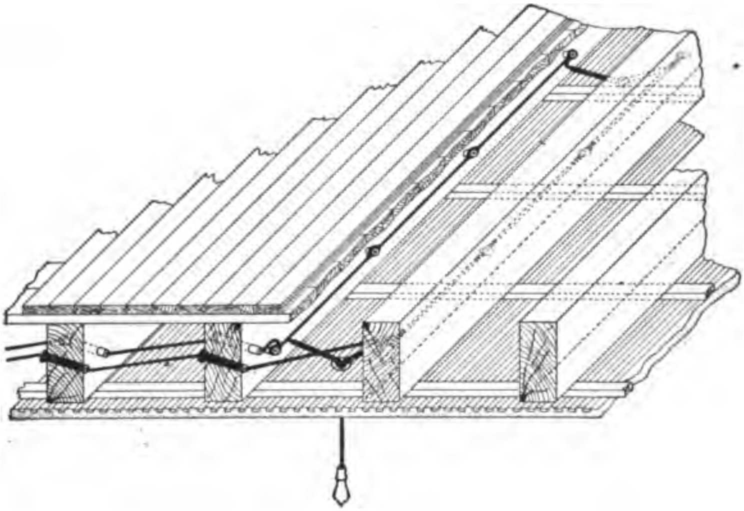


Fig. 15. Knob and Tube Wiring.

Fig. 15 shows an example of knob and tube wiring. In concealed knob and tube wiring, the wires must be separated at least ten inches from one another, and at least one inch from the surface wired over, that is, from the beams, flooring, etc., to which the insulator is fastened. Fig. 16 shows a good type of porcelain knob for this class of wiring. For knob and tube wiring, it will be noted that, owing to the fact that the wiring is concealed, the conductors must be kept further apart than in the case of exposed or open wiring on insulators, where, except in damp places, the wires may be run on cleats or on insulators only one-half inch from the surface wired over.

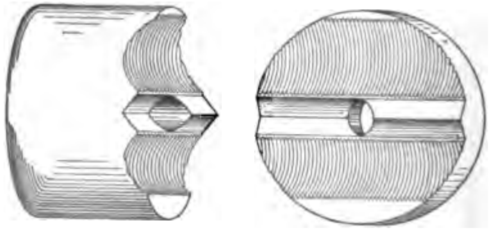


Fig. 16. Porcelain Knob.

Fibrous Tubing. Fibrous tubing is frequently used with knob and tube wiring, and the regulations governing its use are given in Rule 24, Section S, of the *National Electric Code.* This tubing, as stated in this *Rule,* may be used where it is impossible and impracticable to employ knobs and tubes, provided the difference in potential between the wires is not over 300 volts, and if the wires are not subject to moisture. The cost of wiring in flexible fibrous tubing is approximately about the same as the cost of knob and tube wiring. Duplex conductors, or two wires together are not allowed in fibrous tubing.

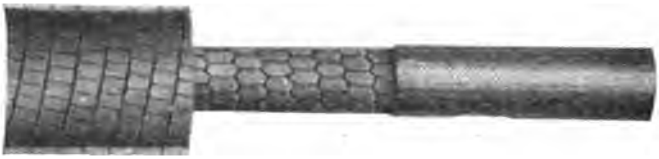


Fig. 17. Flexible Tubing, "Flexduct" Type.
Courtesy of National Metal Molding Co., Pittsburg, Pa.

Fibrous tubing is required at all outlets where conduit or armored cable is not used (as in knob and tube wiring); and, as required by the *Rules,* it must extend back from the last porcelain support to one inch beyond the outlet. Fig. 17 shows one make of fibrous tubing.

Table VIII gives the maximum sizes of conductors (double-braided) which may be installed in fibrous conduit.

TABLE VIII

Sizes of Conductors in Fibrous Conduit

Outside Diameter	Inside Diameter	One Wire in Tube
$\frac{17}{32}$ inch	$\frac{1}{4}$ inch	No. 12
$\frac{21}{32}$ "	$\frac{3}{8}$ "	" 8
$\frac{25}{32}$ "	$\frac{1}{2}$ "	" 6
$\frac{15}{16}$ "	$\frac{5}{8}$ "	" 1
$1\frac{3}{32}$ "	$\frac{3}{4}$ "	" 2/0
$1\frac{5}{16}$ "	1 "	250,000 C. M.
$1\frac{9}{16}$ "	$1\frac{1}{4}$ "	400,000 C. M.
$1\frac{13}{16}$ "	$1\frac{1}{2}$ "	750,000 C. M.
$2\frac{1}{8}$ "	$1\frac{3}{4}$ "	1,000,000 C. M.
$2\frac{3}{8}$ "	2 "	1,500,000 C. M.
$2\frac{5}{8}$ "	$2\frac{1}{4}$ "	2,000,000 C. M.

WIRES RUN EXPOSED ON INSULATORS

This method of wiring has the advantages of cheapness, durability, and accessibility.

Cheapness. The relative cost of this method of wiring as compared with that of the concealed conduit system, is about fifty per cent of the latter if rubber-covered conductors are used, and about forty per cent of the latter if weatherproof slow-burning conductors are used. As the *Rules* of the Fire Underwriters allow the use of weatherproof slow-burning conductors in dry places, considerable saving may be effected by this method of wiring, provided there is no objection to it from the standpoint of appearance, and also provided that it is not liable to mechanical injury or disarrangement.

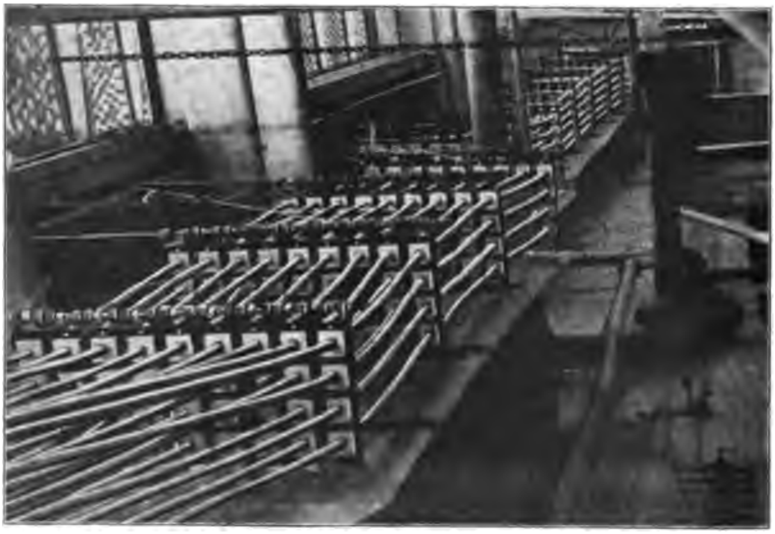


Fig. 18. Large Feeders Run Exposed on Insulators.

Durability. It is a well-known fact that rubber insulation has a relatively short life. Inasmuch as in this method of wiring, the insulation does not depend upon the insulation of the conductors, but on the insulators themselves, which are of glass or porcelain, this system is much more desirable than any of the other methods. Of course, if the conductors are mechanically injured, or the insulators broken, the insulation of the system is reduced; but there is no gradual deterioration as there is in the case of other methods of wiring, where rubber is depended upon for insulation. This is especially true in hot places, particularly where the temperature is 120° F. or above. For such cases, the weatherproof slow-burning conductors on porcelain or glass insulators are especially recommended.

Accessibility. The conductors being run exposed, they may be readily repaired or removed, or connections may be made to the same. This method of wiring is especially recommended for mills, factories, and for large or long feeder conductors. Fig. 18 shows examples of exposed large feeder conductors, installed in the New York Life Insurance Building, New York City. For small conductors, up to say No. 6 B. & S. Gauge each, porcelain cleats may be used to support one, two, or three conductors, provided the distance between the conductors is at least 2½ inches in a two-wire system, and 2½ inches between the two outside conductors in a three-wire system where the potential between the outside conductors is not over 300 volts. The cleat must hold the wire at least one-half inch from the surface to which the cleat is fastened; and in damp places the wire must be held at least one inch from the surface wired over. For larger conductors,

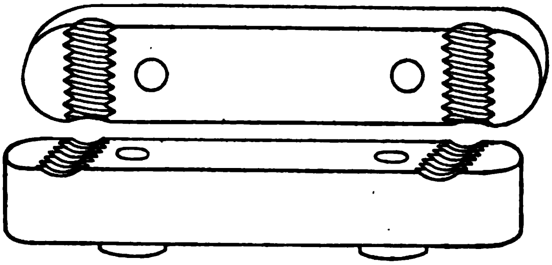


Fig. 19. Two-Wire Cleat.

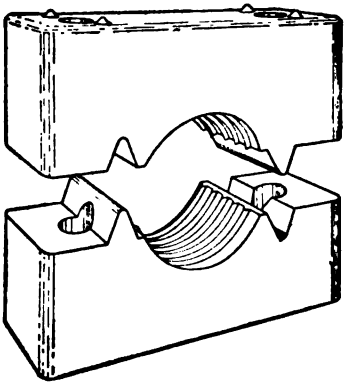


Fig. 20. One-Wire Cleat.

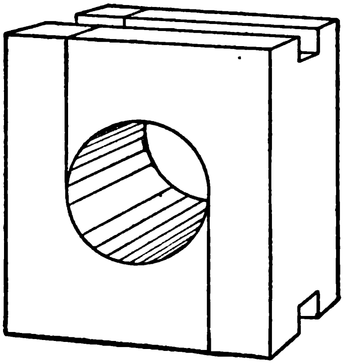


Fig. 21. Porcelain Insulator for Large Conductors.

from No. 6 to No. 4/0 B. & S. Gauge, it is usual to use single porcelain cleats or knobs. Figs. 19 and 20 show a good form of two-wire cleat and single-wire cleat, respectively.

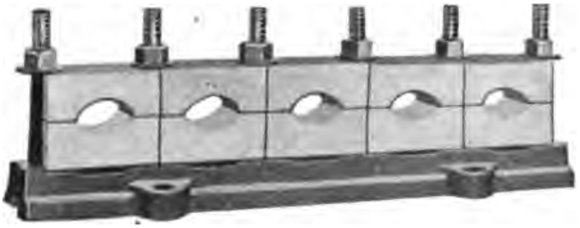


Fig. 22. Iron Rack and Insulators for Large Conductors.
Courtesy of General Electric Co., Schenectady, N. Y.

For large feeder or main conductors from No. 4/0 B. & S. Gauge upward, a more substantial form of porcelain insulator should be used, such as shown in Fig. 21. These insulators are held in iron racks or angle-iron frames, of which two forms are shown in Figs. 22 and 23. The latter form of rack is particularly desirable for heavy conductors and where a number of conductors are run together. In this form of rack, any length of conductor can be removed without disturbing the other conductors.

As a rule, the porcelain insulators should be placed not more than 4½ feet apart; and if the wires are liable to be disturbed, the distance between supports should be shortened, particularly for small conductors. If the beams are so far apart that supports cannot be obtained every 4½ feet, it is necessary to provide a running board as shown in Fig. 24, to which the porcelain cleats and knobs can be fastened. Figs. 25 and 26 show two methods of supporting small conductors. For conductors of No. 8 B. & S.

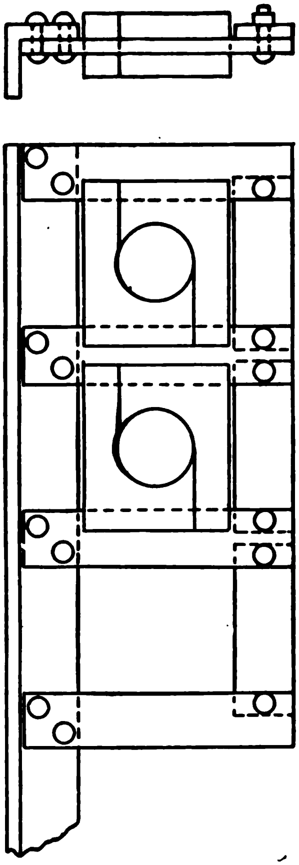


Fig. 23. Elevation and Plan of Insulators Held in Angle-Iron Frames.

Gauge, or over, it is not necessary to break around the beams, provided they are not liable to be disturbed; but the supports may be placed on each beam.

Where the distance between the supports, however, is greater than 4½ feet, it is usually necessary to provide intermediate supports, as shown in Fig. 27, or else to provide a running-board. Another method which may be used, where beams are further than 4½ feet apart, is to run a main along the wall at right angles to the beams, and to have the individual circuits run between and parallel to the beams.

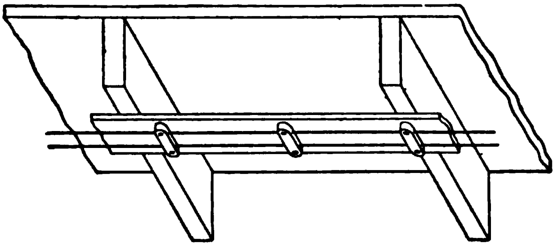


Fig. 24. Insulators Mounted on Running-Board across Wide-Spaced Beams.

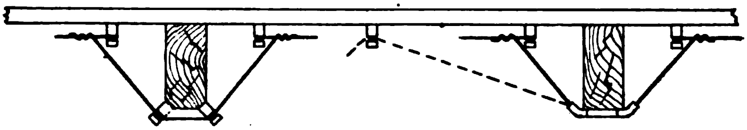


Fig. 25. Method of Supporting Small Conductors.

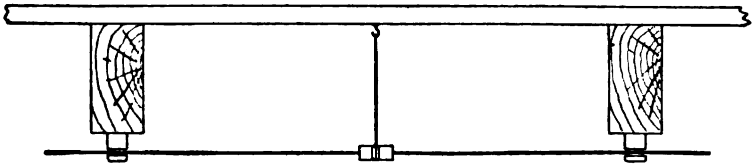


Fig. 27. Intermediate Support for Conductor between Wide-Spaced Beams.

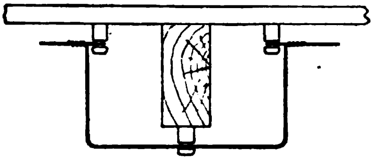


Fig. 26. Method of Supporting a Small Conductor.

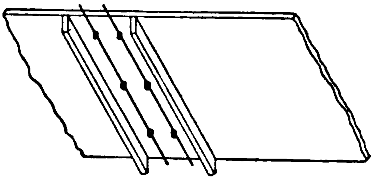


Fig. 28. Conductors Protected by Wooden Guard Strips on Low Ceiling.

In low-ceiling rooms, where the conductors are liable to injury, it is usually required that a wooden guard strip be placed on each side of the conductors, as shown in Fig. 28.

Where the conductors pass through partitions or walls, they must be protected by porcelain tubes, or, if the conductors be of rubber, by means of fibrous tubing placed inside of iron conduits.

All conductors on the walls for a height of not less than six feet from the ground, either should be boxed in, or, if they be rubber-covered, should (preferably) be run in iron conduits; and in conductors having single braid only, additional protection should be provided by means of flexible tubing placed inside of the iron conduit.

Where conductors cross each other, or where they cross iron pipes, they should be protected by means of porcelain tubes fastened with tape or in some other substantial manner that will prevent the tubes from slipping out of place.

TWO-WIRE AND THREE-WIRE SYSTEMS

As both the two-wire and the three-wire system are extensively used in electric wiring, it will be well to give some consideration to the advantages and disadvantages of each system, and to explain them somewhat in detail.

Relative Advantages. The choice of either a two-wire or a three-wire system depends largely upon the source of supply. If, for example, the source of supply will always probably be a 120-volt, two-wire system, there would be no object in installing a three-wire system for the wiring. If, on the other hand, the source of supply is a 120-240-volt system, the wiring should, of course, be made three-wire. Furthermore, if at the outset the supply were two-wire, but with a possibility of a three-wire system being provided later, it would be well to adapt the electric wiring for the three-wire system, making the neutral conductor twice as large as either of the outside conductors, and combining the two outside conductors to make a single conductor until such time as the three-wire service is installed. Of course, there would be no saving of copper in this last-mentioned three-wire system, and in fact it would be slightly more expensive than a two-wire system, as will be shortly explained.

The object of the three-wire system is to reduce the amount of copper—and consequently the cost of wiring—necessary to transmit a given amount of electric power. As a rule, the proposition is usually one of lighting and not of power, for the reason that by means of the three-wire system we are able to increase the potential at which the current is transmitted, and at the same time to take advantage of the greater efficiency of the lower voltage lamp. If current for power (motors, etc.) only were to be transmitted, it would be a simple matter to wind the motors, etc., for a higher voltage, and thereby reduce the weight of copper. If, however, we increase the voltage of lamps, we find that they are not so efficient, nor is their life so long. With the standard carbon lamp, it has been found that the 240-volt lamp, with the same life, requires about 10 to 12 per cent more current than the corresponding 120-volt lamp. Furthermore, in the case of the more efficient lamps recently introduced (such as the Tantalum lamp, Tungsten lamp, etc.), it has been found impracticable, if not impossible, to make them for pressures above 125 volts. For this reason the three-wire system is employed, for by this method we can use 240 volts across the outside conductors, and by the use of a neutral conductor obtain 120 volts between the neutral and the outside conductor, and thereby be enabled to use 120-volt lamps. Furthermore, if a 240-volt lamp should ever be placed on the market that was as economical as the lower voltage lamp, the result would be that the 240-480-volt system would be introduced, and 240-volt lamps used. As a matter of fact, this has been tried in several cities—and particularly in Providence, Rhode Island. As a rule, however, the 120-volt lamp has been found so much more satisfactory as regards life, efficiency, etc., that it is nearly always employed.

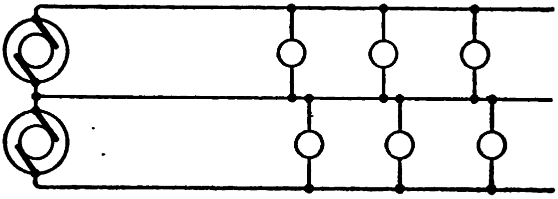


Fig. 29. Three-Wire System, with Neutral Conductor between the Two Outside Conductors.

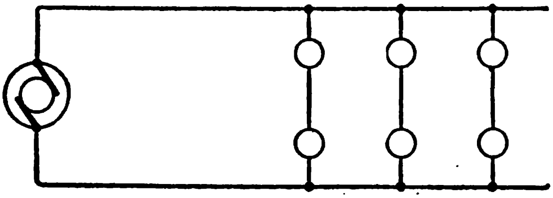


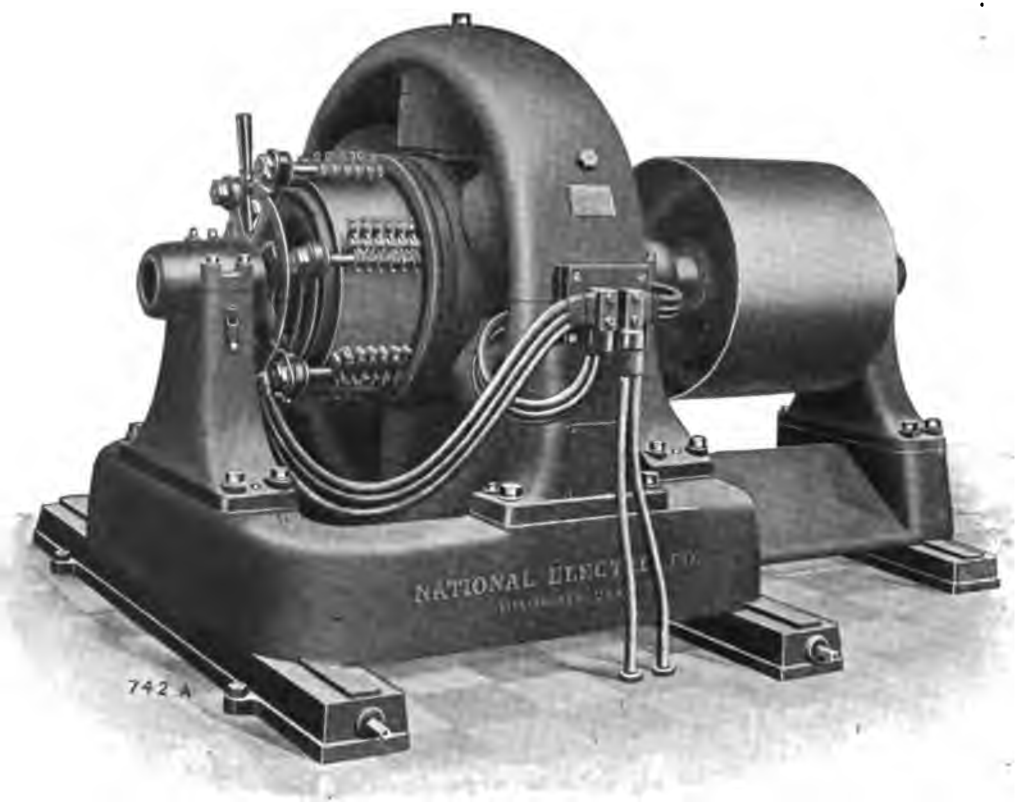
Fig. 30. Lamps Arranged in Pairs in Series, Dispensing with Necessity for Third or Neutral Conductor.

The two-wire system is so extremely simple that no explanation whatever is required concerning it.

The three-wire system, however, is somewhat confusing, and will now be considered.

Details of Three-Wire System. The three-wire system may be considered as a two-wire system with a third or neutral conductor placed between the two outside conductors, as shown in Fig. 29. This neutral conductor would not be required if we could always have the lamps arranged in pairs, as shown in Fig. 30. In this case, the two lamps would burn in series, and we could transmit the current at double the usual voltage, and thereby supply twice the number of lamps with one-quarter the weight of copper, allowing the same loss in pressure in the lamps. The reason for this is, that, having the lamps arranged in series of pairs, we reduce the current to one-half, and, as the pressure at which the current is transmitted is doubled, we can again reduce the copper one-half without increasing the loss in lamps. We therefore see that we have a double saving, as the current is reduced one-half, which reduces the weight of copper one-half, and we can again reduce the copper one-half by doubling the loss in volts without increasing the percentage loss. For example, if in one case we had a straight two-wire system transmitting current to 100 lamps at a potential of 100 volts, and this system were replaced by one in which the lamps were placed in series of pairs, as shown in Fig. 30, and the potential increased to 200 volts—100 lamps still being used—we should find, in the latter case, that we were carrying current really for only 50 lamps, as we would require only the same amount of current for two lamps now that we required for one lamp before. Furthermore, as the potential would now be 200 instead of 100 volts, we could allow twice as much loss as in the first case, because the loss would now be figured as a percentage of 200 volts instead of a percentage of 100 volts. From this, it will readily be seen that in the second case mentioned, we would require only one-quarter the weight of copper that would be required in the first case.

It will readily be seen, however, that a system such as that outlined in the second scheme having two lamps, would be impracticable for ordinary purposes, for the reason that it would always require the lamps to be burned in pairs. Now, it is for this very reason that the third or neutral conductor is required; and, if this conductor be added, it will no longer be necessary to burn the lamps in pairs. This, then, is the object of the three-wire system—to enable us to reduce the amount of copper required for transmitting current, without increasing the electric pressure employed for the lamps.



"NATIONAL" THREE-BEARING BELTED GENERATOR.

150 K.W., 250 Volt, 500 R.P.M.

With regard to the size of the neutral conductor, one important point must be borne in mind; and that is, that the *Rules of the National Electric Code* require the neutral conductor in all interior wiring to be made at least as large as either of the two outside conductors. The reasons for this from a fire standpoint are obvious, because, if for any reason either of the outside conductors became disconnected, the neutral wire might be required to carry the same current as the outside conductors, and therefore it should be of the same capacity. Of course, the chances of such an event happening are slight; but, as the fire hazard is all-important, this rule must be complied with for interior wiring or in all cases where there would be a probability of fire. For outside or underground work, however, where the fire hazard would be relatively unimportant, the neutral conductor might be reduced in size; and, as a matter of fact, it is made smaller than the outside conductors.

The three-wire system is sometimes installed where it is desired to use the system as a two-wire, 125-volt system, or to have it arranged so that it may be used at any time also as a three-wire, 125-250-volt system. Of course, in order to do this, it is necessary to make the neutral conductor equal to the combined capacity of the outside conductors, the latter being then connected together to form one conductor, the neutral being the return conductor. This system is not recommended except in such instances, for example, as where an isolated plant of 125 volts is installed, and where there is a possibility of changing over at some future time to the three-wire, 125-250-volt system. In such a case as this, however, it would be better, where possible, to design the isolated plant for a three-wire, 125-250-volt system originally, and then to make the neutral conductor the same size as each of the two outside conductors.

The weight of copper required in a three-wire system where the neutral conductor is the same size as either of the two outside conductors, is $\frac{3}{8}$ of that required for a corresponding two-wire system using the same voltage of lamps.* It is obvious that this is true, because, as the discussion proved concerning the arrangement shown in Fig. 30, where the lamps were placed in series of pairs, we found that the weight of copper for the two conductors was one-quarter the weight of the regular two-wire system. It is then of course true, that, if we had another conductor of the same size as each of the outside conductors, we increase theweight of copper one-half, or one-quarter plus one-half of one-quarter—that is, three-eighths.

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*Note.—If, in the two-wire system, we represent the weight of each of the two conductors by $\frac{1}{2}$, the weight of each of the outside conductors in a three-wire system would be represented by $\frac{1}{8}$; and if we had three conductors of the same size, we would have $\frac{1}{8} + \frac{1}{8} + \frac{1}{8} = \frac{3}{8}$ of the weight of copper required in a three-wire system, which would be required in a corresponding two-wire system having the same percentage of loss and using the same voltage of lamps.

If the neutral conductor were made $\frac{1}{2}$ of the size of each of the outside conductors, as is sometimes done in underground work, the total weight of copper required would be $\frac{1}{8} + \frac{1}{8} + \frac{1}{16} = \frac{5}{16}$ of that required in the corresponding two-wire system.

In the three-wire system frequently used in isolated plants in which the two outside conductors are joined together and the neutral conductor made equal to their combined capacity, there is no saving of copper, for the reason that the same voltage of transmission is used, and, consequently, we have neither reduced the current nor increased the potential. Furthermore, though the weight of copper is the same, it is now divided into three conductors, instead of two, and naturally it costs relatively more to insulate and manufacture three conductors than to insulate and manufacture two conductors having the same total weight of copper. As a matter of fact, the three-wire system, having the neutral conductor equal to the combined capacity of the two outside ones, the latter being joined together, is about 8 to 10 per cent more expensive than the corresponding straight two-wire system.

In interior wiring, as a rule, where the three-wire system is used for the mains and feeders, the two-wire system is nearly always employed for the branch circuits. Of course, the two-wire branch circuits are then balanced on each side of the three-wire system, so as to obtain as far as possible at all times an equal balance on the two sides of the system. This is done so as to have the neutral conductor carry as little current as possible. From what has already been said, it is obvious that in case there is a perfect balance, the lamps are virtually in series of pairs, and the neutral conductor does not carry any current. Where there is an unbalanced condition, the neutral conductor carries the difference between the current on one side and the current on the other side of the system. For example, if we had five lamps on one side of the system and ten lamps on the other, the neutral conductor would carry the current corresponding to five lamps.

In calculating the three-wire system, the neutral conductor is disregarded, the outer wires being treated as a two-wire circuit, and the calculation is for one-half the total number of lamps, the percentage of loss being based on the potential across the two outside conductors.

The three-wire system is very generally employed in alternating-current secondary wiring, as nearly all transformers are built with three-wire connections.

While unbalancing will not affect the total loss in the outside conductors, yet it does affect the loss in the lamps, for the reason that the system is usually calculated on the basis of a perfect balance, and the loss is divided equally between the two lamps (the latter being considered in series of pairs). If, however, there is unbalancing to a great degree, the loss in lamps will be increased; and if the entire load is thrown over on one side, the loss in the lamps will be doubled on the remaining side, because the total loss in voltage will now occur in these lamps, whereas, in the case of perfect balance, it would be equally divided between the two groups of lamps.

CALCULATION OF SIZES OF CONDUCTORS

The formula for calculating the sizes of conductors for direct currents, where the length, load, and loss in volts are given, is as follows:

The size of conductor (in circular mils) is equal to the current *multiplied by* the distance (one way), *multiplied by* 21.6, *divided by* the loss in volts; or,

$$CM = \frac{C \times D \times 21.6}{V} \dots\dots\dots\dots\dots (1)$$

in which C = Current, in amperes;

D = Distance or length of the circuit (one way, in feet);

V = Loss in volts between the beginning and end of the circuit.

The constant (21.6) of this formula is derived from the resistance of a mil foot of wire of 98 per cent conductivity at 25° Centigrade or 77° Fahrenheit. The resistance of a conductor of one mil diameter and one foot long, is 10.8 at the temperature and conductivity named. We multiply this figure (10.8) by 2, as the length of a circuit is usually given as the distance one way, and in order to obtain the resistance of both conductors in a two-wire circuit, we must multiply by 2. The formula as above given, therefore, is for a two-wire circuit; and in calculating the size of conductors in a three-wire system, the calculation should be made on a two-wire basis, as explained hereinafter.

Formula **1** can be transformed so as to obtain the loss in a given circuit, or the current which may be carried a given distance with a stated loss, or to obtain the distance when the other factors are given, in the following manner:

Formula for Calculating Loss in Circuit when Size, Current, and Distance are Given

$$V = \frac{C \times D \times 21.6}{CM} \quad \ldots\ldots\ldots\ldots\ldots (2)$$

Formula for Calculating Current which may be Carried by a Given Circuit of Specified Length, and with a Specified Loss

$$C = \frac{CM \times V}{D \times 21.6} \quad \ldots\ldots\ldots\ldots\ldots (3)$$

Formula for Calculating Length of Circuit when Size, Loss, and Current to be Carried are Given

$$D = \frac{CM \times V}{C \times 21.6} \quad \ldots\ldots\ldots\ldots\ldots (4)$$

Formulæ are frequently given for calculating sizes of conductors, etc., where the load, instead of being given in amperes, is stated in lamps or in horse-power. It is usually advisable, however, to reduce the load to amperes, as the efficiency of lamps and motors is a variable quantity, and the current varies correspondingly.

It is sometimes convenient, however, to make the calculation in terms of watts. It will readily be seen that we can obtain a formula expressed in watts from Formula **1**. To do this, it is advisable to express the loss in volts in percentage, instead of actual volts lost. It must be remembered that, in the above formulæ, V represents the volts lost in the circuit, or, in other words, the difference in potential between the beginning and the end of the circuit, and is not the applied E. M. F. The loss in percentage, in any circuit, is equal to the actual loss expressed in volts, *divided by* the line voltage, *multiplied by* 100; or,

$$P = \frac{V}{E} \times 100.$$

From this equation, we have:

$$V = \frac{P\,E}{100}.$$

If, for example, the calculation is to be made on a loss of 5 per cent, with an applied voltage of 250, using this last equation, we would have:

$$V = \frac{5 \times 250}{100} = 12.5 \text{ volts.}$$

Substituting the equation $V = \frac{P\,E}{100}$ in Formula **1**, we have:

$$C\,M = \frac{C \times D \times 21.6}{\frac{P\,E}{100}}$$

$$= \frac{C \times D \times 21.6 \times 100}{P\,E}$$

$$= \frac{C \times D \times 2{,}160}{P\,E}.$$

This equation, it should be remembered, is expressed in terms of applied voltage. Now, since the power in watts is equal to the applied voltage *multiplied by* the current ($W = EC$), it follows that

$$C = \frac{W}{E}.$$

By substituting this value of C in the equation given above $\left(C\,M = \frac{C \times D \times 2{,}160}{P\,E}\right)$, the formula is expressed in terms of watts instead of current, thus:

$$CM = \frac{W \times D \times 2{,}160}{E\,P\,E}, \ldots\ldots\ldots\ldots \textbf{(5)}$$

in which W = Power in watts transmitted;
D = Length of the circuit (one way)—that is, the length of one conductor;
P = Figure representing the percentage loss;
E* = Applied voltage.

All the above formulæ are for calculations of two-wire circuits. In making calculations for three-wire circuits, it is usual to make the calculation on the basis of the two outside conductors; and in three wire calculations, the above formulæ can be used with a slight modification, as will be shown.

In a three-wire circuit, it is usually assumed in making the calculation, that the load is equally balanced on the two sides of the neutral conductor; and, as the potential across the outside conductors is double that of the corresponding potential across a two-wire circuit, it is evident that for the same size of conductor the total loss in volts could be doubled without increasing the percentage of loss in lamps. Furthermore, as the load on one side of the neutral conductor, when the system is balanced, is virtually in series with the load on the third side, the current in amperes is usually one-half the sum of the current required by all the lamps.. If C be still taken as the total current in amperes (that is, the sum of the current required by all of the lamps) in Formula 1, we shall have to divide this current by 2, to use the formula for calculating the two outside conductors for a three-wire system. Furthermore, we shall have to multiply the voltage lost in the lamps by 2, to obtain the voltage lost in the two outside conductors, for the reason that the potential of the outside conductors is double the potential required by the lamps themselves. In other words, Formula 1 will become:

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*NOTE. Remember that V in Formulæ 1 to 4 represents the volts lost, but that E in Formula 5 represents the applied voltage.

$$CM = \frac{C \times D \times 21.6}{2 \times V \times 2} = \frac{C \times D \times 21.6}{4V}, \ldots\ldots\ldots\ldots\ldots (6)$$

in which C = Sum of current required by all of the lamps on both sides of the neutral conductor;

D = Length of circuit—that is, of any one of the three conductors;

V = Loss allowed in the lamps, i. e., one-half the total loss in the two outside conductors.

In the same manner, all of the other formulæ may be adapted for making calculations for three-wire systems. Of course the calculation of a three-wire system could be made as if it were a two-wire system, by taking one-half the total number of lamps supplied, at one-half the voltage between the outside conductors.

It is understood, of course, that the size of the conductor in Formula 6 is the size of each of the two outside ones; but, inasmuch as the *Rules of the National Electric Code* require that for interior wiring the neutral conductor shall be at least equal in size to the outside conductors, it is not necessary to calculate the size of the neutral conductor. It must be remembered, however, that, in a three-wire system where the neutral conductor is made equal in capacity to the combined size of the two outside conductors, and where the two outside conductors are joined together, we have virtually a two-wire system arranged so that it can be converted into a three-wire system later. In this case the calculation is exactly the same as in the case of the two-wire circuits, except that one of the two conductors is split into two smaller wires of the same capacity. This is frequently done where isolated plants are installed, and where the generators are wound for 125 volts and it may be desired at times to take current from an outside three-wire 125-250-volt system.

METHOD OF PLANNING A WIRING INSTALLATION

The first step in planning a wiring installation, is to gather all the data which will affect either directly or indirectly the system of wiring and the manner in which the conductors are to be installed. These data will include: Kind of building; construction of building; space available for conductors; source and system of electric-current supply; and all details which will determine the method of wiring to be employed. These last items materially affect the cost of the work, and are usually determined by the character of the building and by commercial considerations.

Method of Wiring. In a modern fireproof building, the only system of wiring to be recommended is that in which the conductors are installed in rigid conduits; although, even in such cases, it may be desirable, and economy may be effected thereby, to install the larger feeder and main conductors exposed on insulators using weatherproof slow-burning wire. This latter method should be used, however, only where there is a convenient runway for the conductors, so that they will not be crowded and will not cross pipes, ducts, etc., and also will not have too many bends. Also, the local inspection authorities should be consulted before using this method.

For mills, factories, etc., wires exposed on cleats or insulators are usually to be recommended, although rigid conduit, flexible conduit, or armored cable may be desirable.

In finished buildings, and for extensions of existing outlets, where the wiring could not readily or conveniently be concealed, moulding is generally used, particularly where cleat wiring or other exposed methods of wiring would be objectionable. However, as has already been said, moulding should not be employed where there is any liability to dampness.

In finished buildings, particularly where they are of frame construction, flexible steel conduits or armored cable are to be recommended.

While in new buildings of frame construction, knob and tube wiring are frequently employed, this method should be used only where the question of first cost is of prime importance. While armored cable will cost approximately 50 to 100 per cent more than knob and tube wiring, the former method is so much more permanent and is so much safer that it is strongly recommended.

Systems of Wiring. The system of wiring—that is, whether the two-wire or the three-wire system shall be used—is usually determined by the source of supply. If the source of supply is an isolated plant, with simple two-wire generators, and with little possibility of current being taken from the outside at some future time, the wiring in the building should be laid out on the two-wire system. If, on the other hand, the isolated plant is three-wire (having three-wire generators, or two-wire generators with balancer sets), or if the current is taken from an outside source, the wiring in the building should be laid out on a three-wire system.

It very seldom happens that current supply from a central station is arranged with other than the three-wire system inside of buildings, because, if the outside supply is alternating current, the transformers are usually adapted for a three-wire system. For small buildings, on the other hand, where there are only a few lights and where there would be only one feeder, the two-wire system is used. As a rule, however, when the current is taken from an outside source, it is best to consult the engineer of the central station supplying the current, and to conform with his wishes. As a matter of fact, this should be done in any event, in order to ascertain the proper voltage for the lamps and for the motors, and also to ascertain whether the central station will supply transformers, meters, and lamps—for, if these are not thus supplied, they should be included in the contract for the wiring.

Location of Outlets. It is not within the scope of this treatise to discuss the matter of *illumination,* but it is desirable, at this point, to outline briefly the method of procedure.

A set of plans, including elevation and details, if any, and showing decorative treatment of the various rooms, should be obtained from the Architect. A careful study should then be made by the Architect, the Owner, and the Engineer, or some other person qualified to make recommendations as to illumination. The location of the outlets will depend: *First,* upon the decorative treatment of the room, which determines the æsthetic and architectural effects; *second,* upon the type and general form of fixtures to be used, which should be previously decided on; *third,* upon the tastes of the owners or occupants in regard to illumination in general, as it is found that tastes vary widely in regard to amount and kind of illumination.

The location of the outlets, and the number of lights required at each, having been determined, the outlets should be marked on the plans.

The Architect should then be consulted as to the location of the centers of distribution, the available points for the risers or feeders, and the available space for the branch circuit conductors.

In regard to the *rising points for the feeders and mains*, the following precautions should be used in selecting chases:

1. The space should be amply large to accommodate all the feeders and mains likely to rise at that given point. This seems trite and unnecessary, but it is the most usual trouble with chases for risers. Formerly architects and builders paid little attention to the requirements for chases for electrical work; but in these later days of 2-inch and 2½-inch conduit, they realize that these pipes are not so invisible and mysterious as the force they serve to distribute, particularly when twenty or more such conduits must be stowed away in a building where no special provision has been made for them.

2. If possible, the space should be devoted solely to electric wiring. Steam pipes are objectionable on account of their temperature; and these and all other pipes are objectionable in the same space occupied by the electrical conduits, for if the space proves too small, the electric conduits are the first to be crowded out.

The chase, if possible, should be continuous from the cellar to the roof, or as far as needed. This is necessary in order to avoid unnecessary bends or elbows, which are objectionable for many reasons.

In similar manner, the location of *cut-out cabinets or distributing centers* should fulfil the following requirements:

1. They should be accessible at all times.
2. They should be placed sufficiently close together to prevent the circuits from being too long.
3. Do not place them in too prominent a position, as that is objectionable from the Architect's point of view.
4. They should be placed as near as possible to the rising chases, in order to shorten the feeders and mains supplying them.

Having determined the system and method of wiring, the location of outlets and distributing centers, the next step is to lay out the *branch circuits* supplying the various outlets.

Before starting to lay out the branch circuits, a drawing showing the floor construction, and showing the space between the top of the beams and girders and the flooring, should be obtained from the Architect. In fireproof buildings of iron or steel construction, it is almost the invariable practice, where the work is to be concealed, to run the conduits over the beams, under the rough flooring, carrying them between the sleepers when running parallel to the sleepers, and notching the latter when the conduits run across them (see Fig. 31). In wooden frame buildings, the conduits run parallel to the beams and to the furring (see Fig. 32); they are also sometimes run below the beams. In the latter case the beams have to be notched, and this is allowable only in certain places, usually near the points where the beams are supported. The Architect's drawing is therefore necessary in order that the location and course of the conduits may be indicated on the plans.

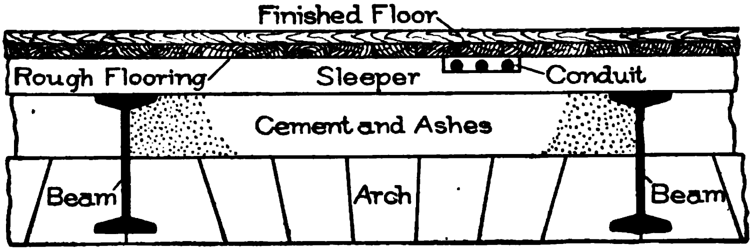

Fig. 31. Running Conductors Concealed under Floor in Fireproof Building.

The first consideration in laying out the branch circuit is the *number of outlets* and *number of lights* to be wired on any one branch circuit. The *Rules of the National Electric Code* (Rule 21-D) require that "no set of incandescent lamps requiring more than 660 watts, whether grouped on one fixture or on several fixtures or pendants, will be dependent on one cut-out." While it would be possible to have branch circuits supplying more than 660 watts, by placing various cut-outs at different points along the route of the branch circuit, so as to subdivide it into small sections to comply with the rule, this method is not recommended, except in certain cases, for exposed wiring in factories or mills. As a rule, the proper method is to have the cut-outs located at the center of distribution, and to limit each branch circuit to 660 watts, which corresponds to twelve or thirteen 50-watt lamps, twelve being the usual limit. Attention is called to the fact that the inspectors usually allow 50 watts for each socket connected to a branch circuit; and although 8-candle-power lamps may be placed at some of the outlets, the inspectors hold that the standard lamp is approximately 50 watts, and for that reason there is always the likelihood of a lamp of that capacity being used, and their inspection is based on that assumption. Therefore, to comply with the requirements, an allowance of not more than twelve lamps per branch circuit should be made.

In ordinary practice, however, it is best to reduce this number still further, so as to make allowance for future extensions or to increase the number of lamps that may be placed at any outlet. For this reason, it is wise to keep the number of the outlets on a circuit at the lowest point consistent with economical wiring. It has been proven by actual practice, that the best results are obtained by limiting the number to five or six outlets on a branch circuit. Of course, where all the outlets have a single light each, it is frequently necessary, for reasons of economy, to increase this number to eight, ten, and, in some cases, twelve outlets.

We have already referred to the location of the wires or conduits. This question is generally settled by the peculiarities of the construction of the building. It is necessary to know this, however, before laying out the circuit work, as it frequently determines the course of a circuit.

Now, as to the course of the circuit work, little need be said, as it is largely influenced by the relative position of the outlets, cut-outs, switches, etc. Between the cut-out box and the first outlet, and between the outlets, it will have to be decided, however, whether the circuits shall run at right angles to the walls of the building or room, or whether they shall run direct from one point to another, irrespective of the angle they make to the sleepers or beams. Of course, in the former case, the advantages are that the cost is somewhat less and the number of elbows and bends is reduced. If the

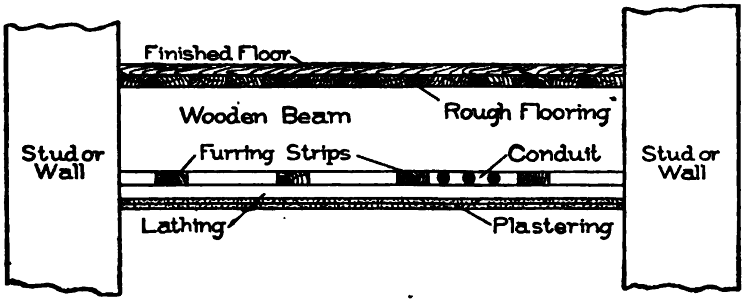

Fig. 32. Running Conductors Concealed under Floor in Wooden Frame Building.

tubes are bent, however, instead of using elbows, the difference in cost is usually very slight, and probably does not compensate for the disadvantages that would result from running the tubes diagonally. As to the number of bends, if branch circuit work is properly laid out and installed, and a proper size of tube used, it rarely happens that there is any difference in "pulling" the branch circuit wires. It may happen, in the event of a very long run or one having a large number of bends, that it might be advisable to adopt a short and most direct route.

Up to this time, the location of the distribution centers has been made solely with reference to architectural considerations; but they must now be considered in conjunction with the branch circuit work.

It frequently happens that, after running the branch circuits on the plans, we find, in certain cases, that the position of centers of distribution may be changed to advantage, or sometimes certain groups may be dispensed with entirely and the circuits run to other points. We now see the wisdom of ascertaining from the Architect where cut-out groups may be located, rather than selecting particular points for their location.

As a rule, wherever possible, it is wise to limit the length of each branch circuit to 100 feet; and the number and location of the distributing centers should be determined accordingly.

It may be found that it is sometimes necessary and even desirable to increase the limit of length. One instance of this may be found in hall or corridor lights in large buildings. It is generally desirable, in such cases, to control the hall lights from one point; and, as the number of lights at each outlet is generally small, it would not be economical to run mains for sub-centers of distribution. Hence, in instances of this character, the length of runs will frequently exceed the limit named. In the great majority of cases, however, the best results are obtained by limiting the runs to 90 or 100 feet.

There are several good reasons for placing such a limit on the length of a branch circuit. To begin with, assuming that we are going to place a limit on the loss in voltage (drop) from the switchboard to the lamp, it may be easily proven that up to a certain reasonable limit it is more economical to have a larger number of distributing centers and shorter branch circuits, than to have fewer centers and longer circuits. It is usual, in the better class of work, to limit the loss in voltage in any branch circuit to approximately one volt. Assuming this limit (one volt loss), it can readily be calculated that the number of lights at one outlet which may be connected on a branch circuit 100 feet long (using No. 14 B. & S. wire), is *four*; or in the case of outlets having a single light each, *five* outlets may be connected on the circuit, the first being 60 feet from the cut-out, the others being 10 feet apart.

These examples are selected simply to show that if the branch circuits are much longer than 100 feet, the loss must be increased to more than one volt, or else the number of lights that may be connected to one circuit must be reduced to a very small quantity, provided, of course, the size of the wire remains the same.

Either of these alternatives is objectionable—the first, on the score of regulation; and the second, from an economical standpoint. If, for instance, the loss in a branch circuit with all the lights turned on is four volts (assuming an extreme case), the voltage at which a lamp on that circuit burns will vary from four volts, depending on the number of lights burning at a time. This, of course, will cause the lamp to burn below candle-power when all the lamps are turned on, or else to diminish its life by burning above the proper voltage when it is the only lamp burning on the circuit. Then, too, if the drop in the branch circuits is increased, the sizes of the feeders and the mains must be correspondingly increased (if the total loss remains the same), thereby increasing their cost.

If the number of lights on the circuit is decreased, we do not use to good advantage the available carrying capacity of the wire.

Of course, one solution of the problem would be to increase the size of the wire for the branch circuits, thus reducing the drop. This, however, would not be desirable, except in certain cases where there were a few long circuits, such as for corridor lights or other special control circuits. In such instances as these, it would be better to increase the sizes of the branch circuit to No. 12 or even No. 10 B. & S. Gauge conductors, than to increase the number of centers of distribution for the sake of a few circuits only, in order to reduce the number of lamps (or loss) within the limit.

The method of calculating the loss in conductors has been given elsewhere; but it must be borne in mind, in calculating the loss of a branch circuit supplying more than one outlet, that separate calculations must be made for each portion of the circuit. That is, a calculation must be made for the loss to the first outlet, the length in this case being the distance from the center of distribution to the first outlet, and the load being the total number of lamps supplied by the circuit. The next step would be to obtain the loss between the first and second outlet, the length being the distance between the two outlets, and the load, in this case, being the total number of lamps supplied by the circuit, *minus* the number supplied by the first outlet; and so on. The loss for the total circuit would be the sum of these losses for the various portions of the circuit.

Feeders and Mains. If the building is more than one story, an elevation should be made showing the height and number of stories. On this elevation, the various distributing centers should be shown diagrammatically; and the current in amperes supplied through each center of distribution, should be indicated at each center. The next step is to lay out a tentative system of feeders and mains, and to ascertain the load in amperes supplied by each feeder and main. The estimated length of each feeder and main should then be determined, and calculation made for the loss from the switchboard to each center of distribution. It may be found that in some cases it will be necessary to change the arrangement of feeders or mains, or even the centers of distribution, in order to keep the total loss from the switchboard to the lamps within the limits previously determined. As a matter of fact, in important work, it is always best to lay out the entire work tentatively in a more or less crude fashion, according to the "cut and dried" method, in order to obtain the best results, because the entire layout may be modified after the first preliminary layout has been made. Of course, as one becomes more experienced and skilled in these matters, the final layout is often almost identical with the first preliminary arrangement.

TESTING

Where possible, two tests of the electric wiring equipment should be made, one after the wiring itself is entirely completed, and switches, cut-out panels, etc., are connected; and the second one after the fixtures have all been installed. The reason for this is that if a ground or short circuit is discovered before the fixtures are installed, it is more easily remedied; and secondly, because there is no division of the responsibility, as there might be if the first test were made only after the fixtures were installed. If the test shows no grounds or short circuits before the fixtures are installed, and one does develop after they are installed, the trouble, of course, is that the short circuit or ground is one or more of the fixtures. As a matter of fact, it is a wise plan always to make a separate test of each fixture after it is delivered at the building and before it is installed.

While a *magneto* is largely used for the purpose of testing, it is at best a crude and unreliable method. In the first place, it does not give an indication, even approximately, of the total insulation resistance, but merely indicates whether there is a ground or short circuit, or not. In some instances, moreover, a magneto test has led to serious errors, for reasons that will be explained. If, as is nearly always the case, the magneto is an alternating-current instrument, it may sometimes happen—particularly in long cables, and especially where there is a lead sheathing on the cable—that the magneto will ring, indicating to the uninitiated that there is a ground or short circuit on the cable. This may be, and usually is, far from being the case; and the cause of the ringing of the magneto is not a ground or short circuit, but is due to the capacity of the cable, which acts as a condenser under certain conditions, since the magneto producing an alternating current repeatedly charges and discharges the cable in opposite directions, this changing of the current causing the magneto to ring. Of course, this defect in a magneto could be remedied by using a commutator and changing it to a direct-current machine; but as the method is faulty in itself, it is hardly worth while to do this.

A portable *galvanometer* with a resistance box and Wheatstone bridge, is sometimes employed; but this method is objectionable because it requires a special instrument which cannot be used for many other purposes. Furthermore, it requires more skill and time to use than the *voltmeter* method, which will now be described.

The advantage of the voltmeter method is that it requires merely a direct-current voltmeter, which can be used for many other purposes, and which all engineers or contractors should possess, together with a box of cells having a potential of preferably over 30 volts. The voltmeter should have a scale of not over 150 volts, for the reason that if the scale on which the battery is used covers too wide a range (say 1,000 volts) the readings might be so small as to make the test inaccurate. A good arrangement would be to have a voltmeter having two scales—say, one of 60 and one of 600—which would make the voltmeter available for all practical potentials that are likely to be used inside of a building. If desired, a voltmeter could be obtained with three connections having three scales, the lowest scale of which would be used for testing insulation resistances.

Before starting a test, all of the fuses should be inserted and switches turned on, so that the complete test of the entire installation can be made. When this has been done, the voltmeter and battery should be connected, so as to obtain on the lowest scale of the voltmeter the electromotive force of the entire group of cells. This connection is shown in Fig. 33. Immediately after this has been done, the insulation resistance to be tested is placed in circuit, whether the insulation to be tested is a switchboard, slate panel-board, or the entire wiring installation; and the connections are made as shown in Fig. 34. A reading should then again be taken of the voltmeter; and the leakage is in proportion to the difference between the first and second readings of the voltmeter. The explanation given below will show how this resistance may be calculated: It is evident that the resistance in the first case was merely the resistance of the voltmeter and the internal resistance of the battery. As a rule, the internal resistance of the battery is so small in comparison with the resistance of the voltmeter and the external resistance, that it may be entirely neglected, and this will be done in the following calculation. In the second case, however, the total resistance in circuits is the resistance of the voltmeter and the battery, *plus* the entire insulation resistance on all the wires, etc., connected in circuit.

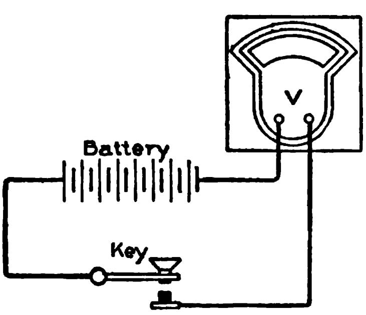

Fig. 33. Connections of Voltmeter and Battery for Testing Insulation Resistance.

To put this in mathematical form, the voltage of the cells may be indicated by the letter E; and the reading of the voltmeter when the insulation resistance is connected by the circuit, by the letter E'. Let R represent the resistance of the voltmeter and R_x represent the insulation resistance of the installation which we wish to measure.

It is a fact which the reader undoubtedly knows, that the E. M. F. as indicated by the voltmeter in Fig. 34 is inversely proportional to the resistance: that is, the greater the resistance, the lower will be the reading on the voltmeter, as this reading indicates the leakage or current passing through the resistance. Putting this in the shape of a formula, we have from the theory of proportion:

$$E : E' :: R + R_x : \mathrm{R} ;$$

or,

$$E' R + E' R_x = E R .$$

Transposing,

$$E' R_x = E R - E' R = R (E - E'),$$

and

$$R_x = \frac{R (E - E')}{E'} .$$

Or, expressed in words, the insulation resistance is equal to the resistance of the voltmeter *multiplied by* the difference between the first reading (or the voltage in the cells) and the second reading (or the reading of the voltmeter with the insulation resistance in series with the voltmeter), *divided by* this last reading of the voltmeter.

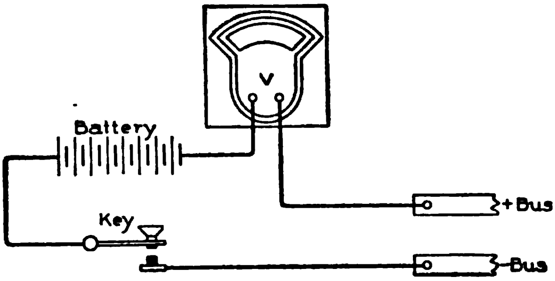

Fig. 34. Insulation Resistance Placed in Circuit, Ready for Testing.

Example. Assume a resistance of a voltmeter (R) of 20,000 ohms, and a voltage of the cells (E) of 30 volts; and suppose that the insulation resistance test of a wiring installation, including switchboard, feeders, branch circuits, panel-boards, etc., is to be made, the insulation resistance being represented by the letter R_x. By substituting in the formula

$$R_x = \frac{R (E - E')}{E'} ,$$

and assuming that the reading of the voltmeter with the insulation resistance connected is 5, we have:

$$R = \frac{20{,}000 \times (30-5)}{5} = 100{,}000 \text{ ohms.}$$

If the test shows an excessive amount of leakage, or a ground or short circuit, the location of the trouble may be determined by the process of elimination—that is, by cutting out the various feeders until the ground or leakage disappears, and, when the feeder on which the trouble exists has been located, by following the same process with the branch circuits.

Of course, the larger the installation and the longer and more numerous the circuits, the greater the leakage will be; and the lower will be the insulation resistance, as there is a greater surface exposed for leakage. The *Rules of the National Electric Code* give a sliding scale for the requirements as to insulation resistance, depending upon the amount of current carried by the various feeders, branch circuits, etc. The rule of the *National Electric Code* (No. 66) covering this point, is as follows:

"The wiring in any building must test free from grounds; *i. e.*, the complete installation must have an insulation between conductors and between all conductors and the ground (not including attachments, sockets, receptacles, etc.) not less than that given in the following table:

Up to	5	amperes	4,000,000	ohms
"	10	"	2,000,000	"
"	25	"	800,000	"
"	50	"	400,000	"
"	100	"	200,000	"
"	200	"	100,000	"
"	400	"	50,000	"
"	800	"	25,000	"
"	1,600	"	12,500	"

"The test must be made with all cut-outs and safety devices in place. If the lamp sockets, receptacles, electroliers, etc., are also connected, only one-half of the resistances specified in the table will be required."

ALTERNATING-CURRENT CIRCUITS

It is not within the province of this chapter to treat the various alternating-current phenomena, but simply to outline the modifications which should be made in designing and calculating electric light wiring, in order to make proper allowance for these phenomena.

The most marked difference between alternating and direct current, so far as wiring is concerned, is the effect produced by self-induction, which is characteristic of all alternating-current circuits. This self-induction varies greatly with conditions depending upon the arrangement of the circuit, the medium surrounding the circuit, the devices or apparatus supplied by or connected in the circuit, etc.

For example, if a coil having a resistance of 100 ohms is included in the circuit, a current of one ampere can be passed through the coil with an electric pressure of 100 volts, if direct current is used; while it might require a potential of several hundred volts to pass a current of one ampere if alternating-current were used, depending upon the number of turns in the coil, whether it is wound on iron or some other non-magnetic material, etc.

It will be seen from this example, that greater allowance should be made for self-induction in laying out and calculating alternating-current wiring, if the conditions are such that the self-induction will be appreciable.

On account of self-induction, the two wires of an alternating-current circuit must never be installed in separate iron or steel conduits, for the reason that such a circuit would be virtually a *choke coil* consisting of a single turn of wire wound on an iron core, and the self-induction would not only reduce the current passing through the circuit, but also might produce heating of the iron pipe. It is for this reason that the *National Electric Code* requires conductors constituting a given circuit to be placed in the same conduit, if that conduit is iron or steel, whenever the said circuit is intended to carry, or is liable to carry at some future time, an alternating current. This does not mean, in the case of a two-phase circuit, that all four conductors need be placed in the same conduit, but that the two conductors of a given phase must be placed in the same conduit. If, however, the three-wire system be used for a two-phase system, all three conductors should be placed in the same conduit, as should also be the case in a three-wire three-phase system. Of course, in a single-phase two- or three-wire system, the conductors should all be placed in the same conduit.

In calculating circuits carrying alternating current, no allowance usually should be made for self-induction when the conductors of the same circuit are placed close together in an iron conduit. When, however, the conductors are run exposed, or are separated from each other, calculation should be made to determine if the effects of self-induction are great enough to cause an appreciable inductive drop. There are several methods of calculating this drop due to self-induction—one by formula, and one by a mathematical method which will be described.

Skin Effect. Skin effect in alternating-current circuits is caused by an incorrect distribution of the current in the wire, the current tending to flow through the outer portion of the wire, it being a well-known fact that in alternating currents, the current density decreases toward the center of the conductor, and that in large wires, the current density at the center of the conductor is relatively quite small.

The skin effect increases in proportion to the square of the diameter, and also in direct ratio to the frequency of the alternating current.

For conductors of No. 0000 B. & S. Gauge, and smaller, and for frequencies of 60 cycles per second, or less, the skin effect is negligible and is less than one-half of one per cent.

For very large cables and for frequencies above 60 cycles per second, the skin effect may be appreciable; and in certain cases, allowance for it should be made in making the calculation. In ordinary practice, however, it may be neglected. Table IX, taken from *Alternating-Current Wiring and Distribution*, by W. R. Emmet, gives the data necessary for calculating the skin effect. The figures given in the first and third columns are obtained by multiplying the size of the conductor (in circular mils) by the frequency (number of cycles per second); and the figures in the second and fourth columns show the factor to be used in multiplying the ohmic resistance, in order to obtain the combined resistance and skin effect.

TABLE IX

Data for Calculating Skin Effect

Product of Circular Mils × Cycles per Sec.	Factor	Product of Circular Mils × Cycles per Sec.	Factor
10,000,000	1.00	70,000,000	1.13
20,000,000	1.01	80,000,000	1.17
30,000,000	1.03	90,000,000	1.20
40,000,000	1.05	100,000,000	1.25
50,000,000	1.08	125,000,000	1.34
60,000,000	1.10	150,000,000	1.43

The factors given in this table, *multiplied by* the resistance to direct currents, will give the resistance to alternating currents for copper conductors of circular cross-section.

Mutual Induction. When two or more circuits are run in the same vicinity, there is a possibility of one circuit inducing an electromotive force in the conductors of an adjoining circuit. This effect may result in raising or lowering the E. M. F. in the circuit in which a mutual induction takes place. The amount of this induced E. M. F. set up in one circuit by a parallel current, is dependent upon the current, the frequency, the lengths of the circuits running parallel to each other, and the relative positions of the conductors constituting the said circuits.

Under ordinary conditions, and except for long circuits carrying high potentials, the effect of mutual induction is so slight as to be negligible, unless the conductors are improperly arranged. In order to prevent mutual induction, the conductors constituting a given circuit should be grouped together. Figs. 35 to 39, inclusive, show five arrangements of two two-wire circuits; and show how relatively small the effect of first induction is when the conductors are properly arranged, as in Fig. 38, and how relatively large it may be when improperly arranged, as in Fig. 39. These diagrams are taken from a publication of Mr. Charles F. Scott, entitled *Polyphase Transmission*, issued by the Westinghouse Electric & Manufacturing Company.

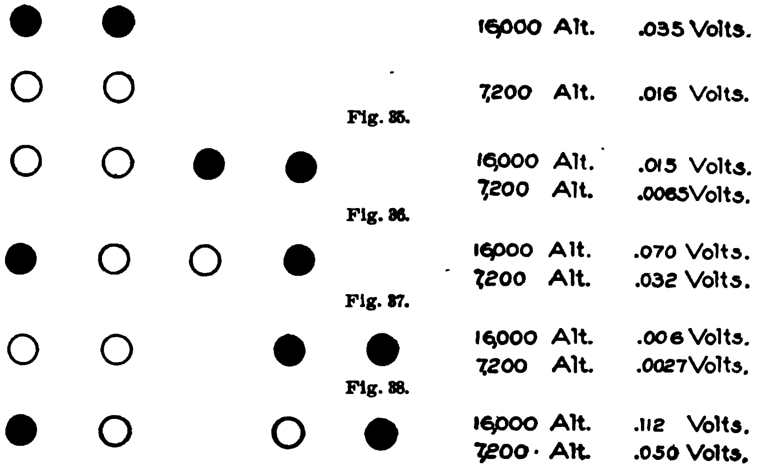

Fig. 35.
Fig. 36.
Fig. 37.
Fig. 38.
Fig. 39.

Various Groupings of Conductors in Two Two-Wire Circuits, Giving Various Effects of Induction.

Line Capacity. The effect of capacity is usually negligible, except in long transmission lines where high potentials are used; no calculations or allowance need be made for capacity, for ordinary circuits.

Calculation of Alternating-Current Circuits. In the instruction paper on "Power Stations and Transmission," a method is given for calculating alternating-current lines by means of formulæ, and data are given regarding power factor and the calculation of both single-phase and polyphase circuits. For short lines, secondary wiring, etc., however, it is probably more convenient to use the chart method devised by Mr. Ralph D. Mershon, described in the *American Electrician* of June, 1897, and partially reproduced as follows:

DROP IN ALTERNATING-CURRENT LINES

When alternating currents first came into use, when transmission distances were short and the only loads carried were lamps, the question of *drop* or *loss of voltage* in the transmitting line was a simple one, and the same methods as for direct current could without serious error be employed in dealing with it. The conditions existing in alternating practice to-day—longer distances, polyphase circuits, and loads made up partly or wholly of induction motors—render this question less simple; and direct-current methods applied to it do not lead to satisfactory results. Any treatment of this or of any engineering subject, if it is to benefit the majority of engineers, must not involve groping through long equations or complex diagrams in search of practical results. The results, if any, must be in available and convenient form. In what follows, the endeavor has been made to so treat the subject of drop in alternating-current lines that if the reader be grounded in the theory the brief space devoted to it will suffice; but if he do not comprehend or care to follow the simple theory involved, he may nevertheless turn the results to his practical advantage.

Calculation of Drop. Most of the matter heretofore published on the subject of drop treats only of the inter-relation of the E. M. F.'s involved, and, so far as the writer knows, there have not appeared in convenient form the data necessary for accurately calculating this quantity. Table X (page 47) and the chart (page 46) include, in a form suitable for the engineer's pocketbook, everything necessary for calculating the drop of alternating-current lines.

The chart is simply an extension of the vector diagram (Fig. 40), giving the relations of the E. M. F.'s of line, load and generator. In

Fig. 40, E is the generator E. M. F.; e, the E. M. F. impressed upon the load; c, that component of E which overcomes the back E. M. F. due to the impedance of the line. The component c is made up of two components at right angles to each other. One is a, the component overcoming the IR or back E. M. F. due to resistance of the line. The other is b, the component overcoming the reactance E. M. F. or back E. M. F. due to the alternating field set up around the wire by the current in the wire. The drop is the difference between E and e. It is d, the radial distance between two circular arcs, one of which is drawn with a radius e, and the other with a radius E.

The chart is made by striking a succession of circular arcs with O as a center. The radius of the smallest circle corresponds to e, the E. M. F. of the load, which is taken as 100 per cent. The radii of the succeeding circles increase by 1 per cent of that of the smallest circle; and, as the radius of the last or largest circle is 140 per cent of that of the smallest, the chart answers for drops up to 40 per cent of the E. M. F. delivered.

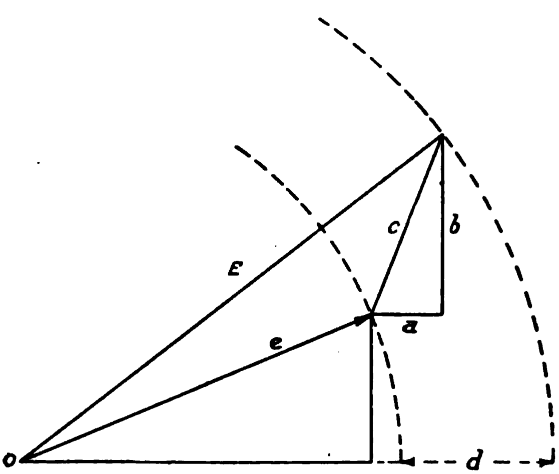

Fig. 40. Vector Diagram.

The terms *resistance volts*, *resistance E. M. F.*, *reactance volts*, and *reactance E. M. F.*, refer, of course, to the voltages for overcoming the back E. M. F.'s due to resistance and reactance respectively. The figures given in the table under the heading "Resistance-Volts for One Ampere, etc." are simply the resistances of 2,000 feet of the various sizes of wire. The values given under the heading "Reactance-Volts, etc.," are, a part of them, calculated from tables published some time ago by Messrs. Houston and Kennelly. The remainder were obtained by using Maxwell's formula.

The explanation given in the table accompanying the chart

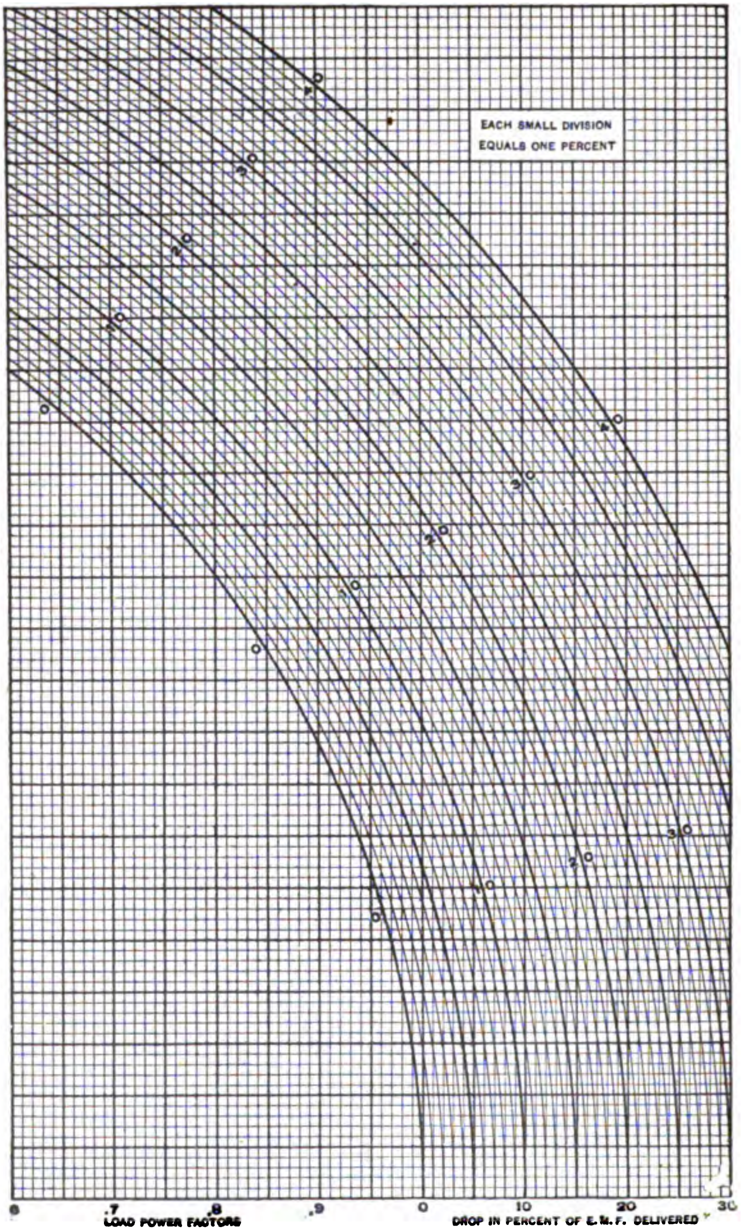

Chart for Calculating Drop in Alternating-Current Lines.

TABLE X

Data for Calculating Drop in Alternating-Current Lines

To be used in conjunction with Chart on opposite page.

By means of the table, calculate the ***Resistance-Volts*** and the ***Reactance-Volts*** in the line, and find what per cent each is of the E. M. F. delivered at the end of the line. Starting from the point on the chart where the vertical line corresponding with the power-factor of the load intersects the smallest circle, lay off in per cent the resistance E. M. F. horizontally and to the right; from the point thus obtained, lay off upward in per cent the reactance-E. M. F. The circle on which the last point falls gives the drop, in per cent, of the E. M. F. delivered at the end of the line. Every tenth circle arc is marked with the per cent drop to which it corresponds.

Throughout the table the lower figures in the squares give values for ONE MILE of line, corresponding to those of the upper figures for 1,000 feet of line.

Upper figures are REACTANCE-VOLTS in 1,000 ft. of Line (= 2,000 ft. of Wire) for One Ampere at 7,200 Alternations per Minute (60 Cycles per Second) for the distance given between Centers of Conductors.

Size of wire—B. & S.	Upper figures are Weight in Lbs. per 1,000 ft. Single Wire	Upper figures are RESISTANCE-VOLTS in 1,000 ft. of Line (2,000 ft. of wire) for One Ampere	½"	1"	2"	3"	6"	9"	12"	18"	24"	30"	36"
0000	639 3,376	.098 .518	.046 .243	.079 .417	.111 .586	.130 .687	.161 .850	.180 .951	.193 1.02	.212 1.12	.225 1.19	.235 1.24	.244 1.29
000	507 2,677	.124 .653	.052 .275	.085 .449	.116 .613	.135 .713	.167 .882	.185 .977	.199 1.05	.217 1.15	.230 1.22	.241 1.27	.249 1.32
00	402 2,123	.156 .824	.057 .301	.090 .475	.121 .639	.140 .739	.172 .908	.190 1.00	.204 1.08	.222 1.17	.236 1.25	.246 1.30	.254 1.34
0	319 1,685	.197 1.04	.063 .332	.095 .502	.127 .671	.145 .766	.177 .935	.196 1.04	.209 1.10	.228 1.20	.241 1.27	.251 1.33	.259 1.37
1	253 1,335	.248 1.31	.068 .359	.101 .533	.132 .687	.151 .797	.183 .966	.201 1.06	.214 1.13	.233 1.23	.246 1.30	.256 1.35	.265 1.40
2	201 1,059	.313 1.65	.074 .391	.106 .560	.138 .728	.156 .824	.188 .993	.206 1.09	.220 1.16	.238 1.26	.252 1.33	.262 1.38	.270 1.43
3	159 840	.394 2.08	.079 .417	.112 .591	.143 .755	.162 .856	.193 1.02	.212 1.12	.225 1.19	.244 1.29	.257 1.36	.267 1.41	.275 1.45
4	126 666	.497 2.63	.085 .449	.117 .618	.149 .787	.167 .882	.199 1.05	.217 1.15	.230 1.22	.249 1.32	.262 1.38	.272 1.44	.281 1.48
5	100 528	.627 3.31	.090 .475	.121 .639	.154 .813	.172 .908	.204 1.08	.223 1.18	.236 1.25	.254 1.34	.268 1.42	.278 1.47	.286 1.51
6	79 419	.791 4.18	.095 .502	.127 .671	.158 .834	.178 .940	.209 1.10	.228 1.20	.241 1.27	.260 1.37	.272 1.44	.283 1.49	.291 1.54
7	63 332	.997 5.27	.101 .533	.132 .697	.164 .866	.183 .966	.214 1.13	.233 1.23	.246 1.30	.265 1.40	.278 1.47	.288 1.52	.296 1.56
8	50 263	1.260 6.64	.106 .560	.138 .729	.169 .893	.188 .993	.220 1.16	.238 1.26	.252 1.33	.270 1.43	.284 1.50	.293 1.55	.302 1.60

(Table X) is thought to be a sufficient guide to its use, but a few examples may be of value.

Problem. Power to be delivered, 250 K.W.; E. M. F. to be delivered, 2,000 volts; distance of transmission, 10,000 feet; size of wire, No. 0; distance between wires, 18 inches; power factor of load, .8; frequency, 7,200 alternations per minute. Find the line loss and drop.

Remembering that the power factor is that fraction by which the apparent power of volt-amperes must be multiplied to give the true power, the apparent power to be delivered is

$$\frac{250\text{ K.W.}}{.8}=312.5\text{ apparent K.W.}$$

The current, therefore, at 2,000 volts will be

$$\frac{312{,}500}{2{,}000}=156.25\text{ amperes.}$$

From the table of reactances under the heading "18 inches," and corresponding to No. 0 wire, is obtained the constant .228. Bearing the instructions of the table in mind, the reactance-volts of this line are, 156.25 (amperes) × 10 (thousands of feet) × .228 = 356.3 volts, which is 17.8 per cent of the 2,000 volts to be delivered.

From the column headed "Resistance-Volts" and corresponding to No. 0 wire, is obtained the constant .197. The resistance-volts of the line are, therefore, 156.25 (amperes) × 10 (thousands of feet) × .197 = 307.8 volts, which is 15.4 per cent of the 2,000 volts to be delivered.

Starting, in accordance with the instructions of the table, from the point where the vertical line (which at the bottom of the chart is marked "Load Power Factor" .8) intersects the inner or smallest circle, lay off horizontally and to the right the resistance-E. M. F. in per cent (15.4); and *from the point thus obtained,* lay off vertically the reactance-E. M. F. in per cent (17.8). The last point falls at about 23 per cent, as given by the circular arcs. This, then, is the drop, in per cent, of *the E. M. F. delivered.* The drop, in per cent, of the *generator* E. M. F. is, of course,

$$\frac{23}{100+23}=18.7\text{ per cent.}$$

The percentage *loss of power* in the line has not, as with direct current, the same value as the percentage drop. This is due to the fact that the line has reactance, and also that the apparent power delivered to the load is not identical with the true power—that is, the load power factor is less than unity. The loss must be obtained by calculating $I^2 R$ for the line, or, what amounts to the same thing, by multiplying the resistance-volts by the current.

The resistance-volts in this case are 307.8, and the current 156.25 amperes. The loss is 307.8 × 156.25=48.1 K. W. The percentage *loss* is

$$\frac{48.1}{250 + 48.1} = 16.1 \text{ per cent.}$$

Therefore, for the problem taken, the *drop* is 18.7 per cent, and the *loss* is 16.1 per cent. If the problem be to find the size wire for a given drop, it must be solved by trial. Assume a size of wire and calculate the drop; the result in connection with the table will show the direction and extent of the change necessary in the size of wire to give the required drop.

The effect of the line reactance in increasing the drop should be noted. If there were no reactance, the drop in the above example would be given by the point obtained in laying off on the chart the resistance-E. M. F. (15.4) only. This point falls at 12.4 per cent, and the drop in terms of the generator E. M. F. would be

$$\frac{12.4}{112.4} = 11 \text{ per cent, instead of } 18.7 \text{ per cent.}$$

Anything therefore which will reduce reactance is desirable.

Reactance can be reduced in two ways. One of these is to diminish the distance between wires. The extent to which this can be carried is limited, in the case of a pole line, to the least distance at which the wires are safe from swinging together in the middle of the span; in inside wiring, by the danger from fire. The other way of reducing reactance is to split the copper up into a greater number of circuits, and arrange these circuits so that there is no inductive interaction. For instance, suppose that in the example worked out above, two No. 3 wires were used instead of one No. 0 wire. The resistance-volts would be practically the same, but the reactance-volts would be less in the ratio $\frac{1}{2} \times \frac{.244}{.228} = .535$, since each circuit would bear half the current the No. 0 circuit does, and the constant for No. 3 wire is .244, instead of .228—that for No. 0. The effect of subdividing the copper is also shown if in the example given it is desired to reduce the drop to, say, one-half. Increasing the copper from No. 0 to No. 0000 will not produce the required result, for, although the resistance-volts will be reduced one-half, the reactance-volts will be reduced only in the ratio $\frac{.212}{.228}$. If, however, *two* inductively independent circuits of No. 0 wire be used, the resistance- and reactance-volts will both be reduced one-half, and the drop will therefore be diminished the required amount.

The component of drop due to reactance is best diminished by subdividing the copper or by bringing the conductors closer together. It is little affected by change in size of conductors.

An idea of the manner in which changes of power factor affect drop is best gotten by an example. Assume distance of transmission, distance between conductors E. M. F., and frequency, the same as in the previous example. Assume the *apparent* power delivered the same as before, and let it be constant, but let the power factor be given several different values; the true power will therefore be a variable depending upon the value of the power factor. Let the size of wire be No. 0000. As the apparent power, and hence the current, is the same as before, and the line resistance is one-half, the resistance-E. M. F. will in this case be

$$\frac{15.4}{2}, \text{ or } 7.7 \text{ per cent of the E. M. F. delivered.}$$

Also, the reactance-E. M. F. will be

$$\frac{.212 \times 17.8}{.228} = 16.5 \text{ per cent.}$$

Combining these on the chart for a power factor of .4, and deducing the drop, in per cent, of the generator E. M. F., the value obtained is 15.3 per cent; with a power factor of .8, the drop is 14 per cent; with a power factor of unity, it is 8 per cent. If in this example the *true* power, instead of the *apparent* power, had been taken as constant, it is evident that the values of drop would have differed more widely, since the current, and hence the resistance- and reactance-volts, would have increased as the power factor diminished. The condition taken more nearly represents that of practice.

If the line had resistance and no reactance, the several values of drop, instead of 15.3, 14, and 8, would be 3.2, 5.7, and 7.2 per cent respectively, showing that for a load of lamps the drop will not be much increased by reactance; but that with a load, such as induction motors, whose power factor is less than unity, care should be taken to keep the reactance as low as practicable. In all cases it is advisable to place conductors as close together as good practice will permit.

When there is a transformer in circuit, and it is desired to obtain the combined drop of transformer and line, it is necessary to know the resistance- and reactance-volts of the transformer. The resistance-volts of the combination of line and transformer are the sum of the resistance-volts of the line and the resistance-volts of the transformer. Similarly, the reactance-volts of the line and transformer are the sum of their respective reactance-volts. The resistance- and reactance-E. M. F.s of transformers may usually be obtained from the makers, and are ordinarily given in per cent.* These percentages express the values of the resistance- and reactance-E. M. F.'s when the transformer delivers its normal *full-load* current; and they express these values in terms of the normal *no-load* E. M. F. of the transformer.

Consider a transformer built for transformation between 1,000 and 100 volts. Suppose the resistance- and reactance-E. M. F.'s given are 2 per cent and 7 per cent respectively. Then the corresponding voltages when the transformer delivers full-load current, are 2 and 7 volts or 20 and 70 volts according as the line whose drop is required is connected to the low-voltage or high-voltage terminals. These values, 2—7 and 20—70, hold, no matter at what voltage the trans-

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*When the required values cannot be obtained from the makers, they may be measured. Measure the resistance of both coils. If the line to be calculated is attached to the high-voltage terminals of the transformer, the equivalent resistance is that of the high-voltage coil, *plus* the resistance obtained by *increasing* in the square of the ratio of transformation the measured resistance of the low-voltage coil That is, if the ratio of transformation is 10, the equivalent resistance referred to the high-voltage circuit is the resistance of the high-voltage coil, *plus* 100 times that of the low-voltage coil. This equivalent resistance multiplied by the high-voltage current gives the transformer resistance-volts referred to the high-voltage circuit. Similarly, the equivalent resistance referred to the low-voltage circuit is the resistance of the low-voltage coil, *plus* that of the high-voltage coil *reduced* in the square of the ratio of transformation. It follows, of course, from this, that the values of the resistance-volts referred to the two circuits bear to each other the ratio of transformation. To obtain the reactance-volts, short-circuit one coil of the transformer and measure the voltage necessary to force through the other coil its normal current at normal frequency. The result is, nearly enough, the reactance-volts. It makes no difference which coil is short-circuited, as the results obtained in one case will bear to those in the other the ratio of transformation. If a close value is desired, subtract from the square of the voltage reading the square of the *resistance*-volts, and take the square root of the difference as the reactance-volts.

former is operated, since they depend only upon the strength of current, providing it is of the normal frequency. If any other than the full-load current is drawn from the transformer, the reactance- and resistance-volts will be such a proportion of the values given above as the current flowing is of the full-load current. It may be noted, in passing, that when the resistance- and reactance-volts of a transformer are known, its regulation may be determined by making use of the chart in the same way as for a line having resistance and reactance.

As an illustration of the method of calculating the drop in a line and transformer, and also of the use of table and chart in calculating low-voltage mains, the following example is given:

Problem. A single-phase induction motor is to be supplied with 20 amperes at 200 volts; alternations, 7,200 per minute; power factor, .78. The distance from transformer to motor is 150 feet, and the line is No. 5 wire, 6 inches between centers of conductors. The transformer reduces in the ratio $\frac{2,000}{200}$, has a capacity of 25 amperes at 200 volts, and, when delivering this current and voltage, its resistance-E. M. F. is 2.5 per cent, its reactance-E. M. F. 5 per cent. Find the drop.

The reactance of 1,000 feet of circuit consisting of two No. 5 wires, 6 inches apart, is .204. The reactance-volts therefore are

$$.204 \times \frac{150}{1,000} \times 20 = .61 \text{ volts.}$$

The resistance-volts are

$$.627 \times \frac{150}{1,000} \times 20 = 1.88 \text{ volts.}$$

At 25 amperes, the resistance-volts of the transformer are 2.5 per cent of 200, or 5 volts. At 20 amperes, they are $\frac{20}{25}$ of this, or 4 volts. Similarly, the transformer reactance-volts at 25 amperes are 10, and at 20 amperes are 8 volts. The combined reactance-volts of transformer and line are $8 + .61 = 8.61$, which is 4.3 per cent of the 200 volts to be delivered. The combined resistance-volts are $1.88 + 4$, or 5.88, which is 2.94 per cent of the E. M. F. to be delivered. Combining these quantities on the chart with a power factor of .78, the drop is 5 per cent of the delivered E. M. F.,

$$\text{or } \frac{5}{105} = 4.8 \text{ per cent}$$

of the impressed E. M. F. The transformer must be supplied with

$$\frac{2,000}{.952} = 2,100 \text{ volts},$$

in order that 200 volts shall be delivered to the motor.

Table X (page 47) is made out for 7,200 alternations, but will answer for any other number if the values for reactance be changed in direct proportion to the change in alternations. For instance, for 16,000 alternations, multiply the reactances given by $\frac{16,000}{7,200}$. For other distances between centers of conductors, interpolate the values given in the table. As the reactance values for different sizes of wire change by a constant amount, the table can, if desired, be readily extended for larger or smaller conductors.

The table is based on the assumption of sine currents and E. M. F.'s. The best practice of to-day produces machines which so closely approximate this condition that results obtained by the above methods are well within the limits of practical requirements.

Polyphase Circuits. So far, single-phase circuits only have been dealt with. A simple extension of the methods given above adapts them to the calculation of polyphase circuits. A four-wire *quarter-phase* (two-phase) transmission may, so far as loss and regulation are concerned, be replaced by two single-phase circuits identical (as to size of wire, distance between wires, current, and E. M. F.) with the two circuits of the quarter-phase transmission, provided that in both cases there is no inductive interaction between circuits. Therefore, to calculate a four-wire, quarter-phase transmission, compute the single-phase circuit required to transmit one-half the power at the same voltage. The quarter-phase transmission will require two such circuits.

A three-wire, *three-phase* transmission, of which the conductors are symmetrically related, may, so far as loss and regulation are concerned, be replaced by two single-phase circuits having no inductive interaction, and identical with the three-phase line as to size, wire, and distance between wires. Therefore, to calculate a three-phase transmission, calculate a single-phase circuit to carry one-half the load at the same voltage. The three-phase transmission will require three wires of the size and distance between centers as obtained for the single-phase.

A three-wire, quarter-phase transmission may be calculated *exactly* as regards loss, and *approximately* as regards drop, in the same way as for three-phase. It is possible to exactly calculate the drop, but this involves a more complicated method than the approximate one. The error by this approximate method is generally small. It is possible, also, to get a somewhat less drop and loss with the same copper by proportioning the cross-section of the middle and outside wires of a three-wire, quarter-phase circuit to the currents they carry, instead of using three wires of the same size. The advantage, of course, is not great, and it will not be considered here.

WIRING AN OFFICE BUILDING

The building selected as a typical sample of a wiring installation is that of an office building located in Washington, D. C. The figures shown are reproductions of the plans actually used in installing the work.

The building consists of a basement and ten stories. It is of fireproof construction, having steel beams with terra-cotta flat arches. The main walls are of brick and the partition walls of terra-cotta blocks, finished with plaster. There is a space of approximately five inches between the top of the iron beams and the top of the finished floor, of which space about three inches was available for running the electric conduits. The flooring is of wood in the offices, but of concrete, mosaic, or tile in the basement, halls, toilet-rooms, etc.

The electric current supply is derived from the mains of the local illuminating company, the mains being brought into the front of the building and extending to a switchboard located near the center of the basement.

As the building is a very substantial fireproof structure, the only method of wiring considered was that in which the circuits would be installed in iron conduits.

Electric Current Supply. The electric current supply is direct current, two-wire for power, and three-wire for lighting, having a potential of 236 volts between the outside conductors, and 118 volts between the neutral and either outside conductor.

Switchboard. On the switchboard in the basement are mounted wattmeters, provided by the local electric company, and the various switches required for the control and operation of the lighting and power feeders. There are a total of ten triple-pole switches for lighting, and eighteen for power. An indicating voltmeter and ampere meter are also placed in the switchboard. A voltmeter is provided with a double-throw switch, and so arranged as to measure the potential across the two outside conductors, or between the neutral conductor and either of the outside conductors. The ampere meter is arranged with two shunts, one being placed in each outside leg; the shunts are connected with a double-pole, double-throw switch, so that the ampere meter can be connected to either shunt and thus measure the current supplied on each side of the system.

Character of Load. The building is occupied partly as a newspaper office, and there are several large presses in addition to the usual linotype machines, trimmers, shavers, cutters, saws, etc. There are also electrically-driven exhaust fans, house pumps, air-compressors, etc. The upper portion of the building is almost entirely devoted to offices rented to outside parties. The total number of motors supplied was 55; and the total number of outlets, 1,100, supplying 2,400 incandescent lamps and 4 arc lamps.

Feeders and Mains. The arrangement of the various feeders and mains, the cut-out centers, mains, etc., which they supply, are shown diagrammatically in Fig. 41, which also gives in schedule the sizes of feeders, mains, and motor circuits, and the data relating to the cut-out panels.

Although the current supply was to be taken from an outside source, yet, inasmuch as there was a probability of a plant being installed in the building itself at some future time, the three-wire system of feeders and mains was designed, with a neutral conductor equal to the combined capacity of the two outside conductors, so that 120-volt two-wire generators could be utilized without any change in the feeders.

Basement. The plan of the basement, Fig. 42, shows the branch circuit wiring for the outlets in the basement, and the location of the main switchboard. It also shows the trunk cables for the interconnection system serving to provide the necessary wires for telephones,

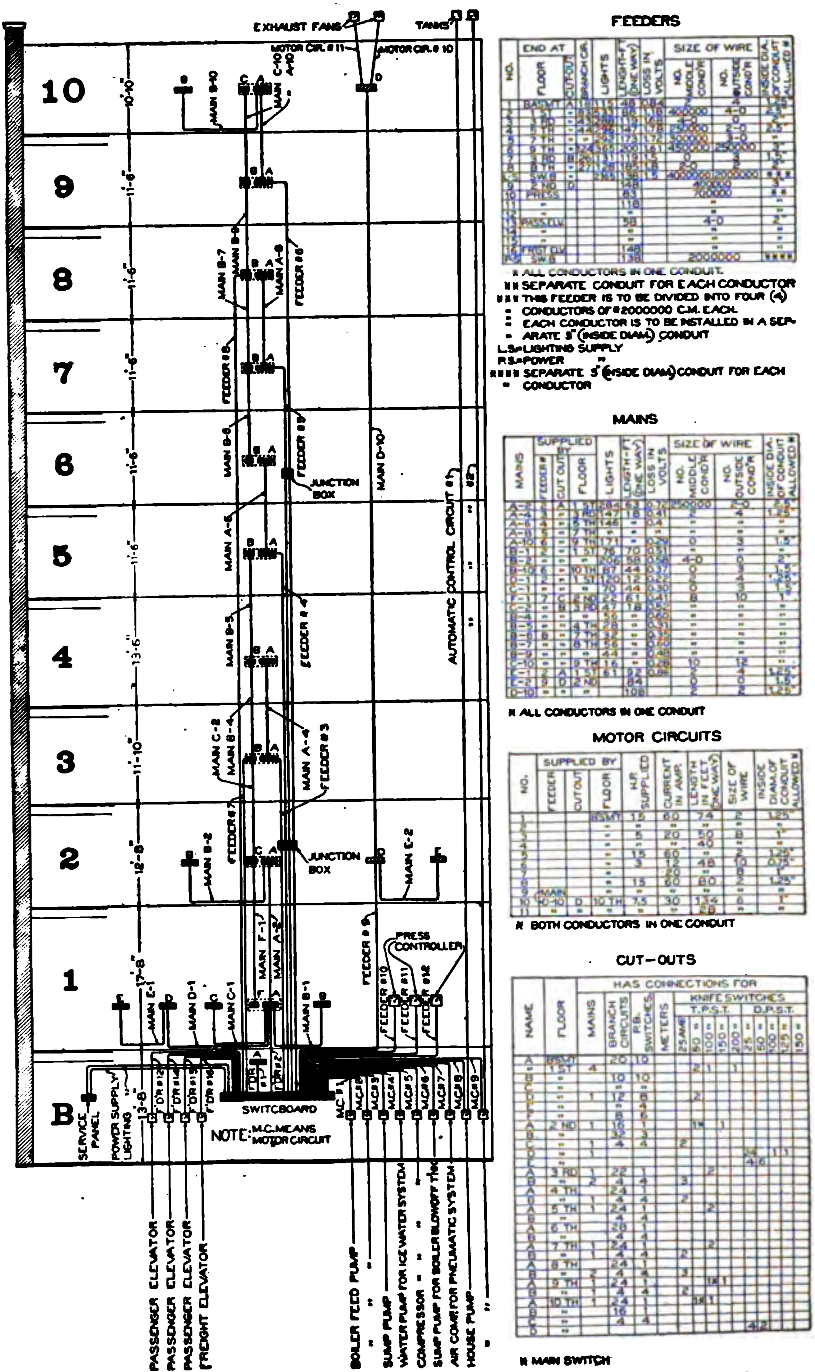
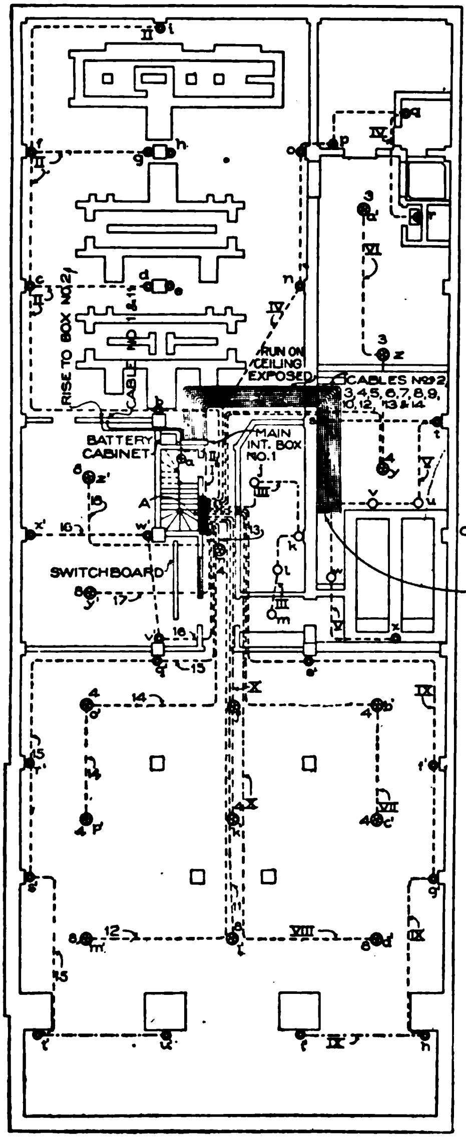


Fig. 41. Wiring of an Office Building. Diagram Showing Arrangement of Feeders and Mains, Cut-Out Centers, etc.



SCHEDULE OF CIRCUITS

NO.	SUPPLIED by CUTOUT	SUPPLIED by MAIN	No. of BRANCHES	OUTLETS SUPPLIED	TOTAL OUTLETS	TOTAL LIGHTS	AT WHAT POINT CONTROLLED
I	A	FOR NO 1	1	a	1	1	
II	"	"	3	bcdefghi	8	8	
III	"	"	1	jklm	4	4	
IV	"	"	1	nopqr	5	5	
V	"	"	1	stuvwx	6	6	
VI	"	"	1	y z a'	3	10	S at A
VII	"	"	1	b'c'	2	8	" " "
VIII	"	"	1	d'	1	8	" " "
IX	"	"	1	e'f'g'h'i'	5	5	
X	"	"	1	j'k'	2	8	S at A
11	"	"	1	l'	1	8	" " "
12	"	"	1	m'	1	8	" " "
13	"	"	1	n'	1	4	" " "
14	"	"	1	o'p'	2	8	" " "
15	"	"	1	q'r's't'u'	5	5	
16	"	"	1	v'w'x'	3	3	
17	"	"	1	y'	1	8	S at A
18	"	"	1	z'	1	8	" " "
					52	115	

CABLE	NO. 2	RISES	TO	2nd	FLOOR
"	" 3	"	"	3rd	"
"	" 4	"	"	4th	"
"	" 5	"	"	5th	"
"	" 6	"	"	6th	"
"	" 7	"	"	7th	"
"	" 8	"	"	8th	"
"	" 9	"	"	9th	"
"	" 10	"	"	10th	"
"	" 12	"	"	2nd	"
"	" 13	"	"	5th	"
"	" 14	"	"	8th	"

Key Showing Explanation of Various Symbols used in Figs. 41 to 46 Inclusive

- ✧--------Ceiling Chandelier
- ●--------Wall Bracket
- ●--------Gooseneck Bracket
- ●--------Wall Socket
- ○--------Drop Cord
- ●--------Arc Lamp
- ✦--------Cooper-Hewitt Lamp
- ●--------Cluster
- ●--------Floor Outlet
- ●--------Desk Light
- #--------Extension Outlet
- ▲--------Push Button Switch
- △--------Snap Switch
- ✚--------Junction Box
- ●--------Electric Clock
- ◘--------Master Clock
- ▨--------Motor Starter
- ▬--------CutOut Panel
- ▭--------Interconnection Box
- ▬--------Power Panel
- ▬--------Pull Box
- ——————Circuit under Floor
- - - - - - " " " above
- —·—·—· " on Ceiling Exposed
- ————Service Line under Floor

Fig. 42. Wiring an Office Building. Basement Plan Showing Branch Circuit Wiring for Outlets in Basement. Location of Main Switchboard, and Trunk Cables of the Interconnection System Providing Wires for Telephone, Ticker, and Messenger Call Service, etc,

tickers, messenger calls, etc., in all the rooms throughout the building, as will be described later.

To avoid confusion, the feeders were not shown on the basement plan, but were described in detail in the specification, and installed in accordance with directions issued at the time of installation. The electric current supply enters the building at the front, and a service switch and cut-out are placed on the front wall. From this point, a two-wire feeder for power and a three-wire feeder for lighting, are run to the main switchboard located near the center of the basement. Owing to the size of the conduits required for these supply feeders, as well as the main feeders extending to the upper floors of the building, the said conduits are run exposed on substantial hangers suspended from the basement ceiling.

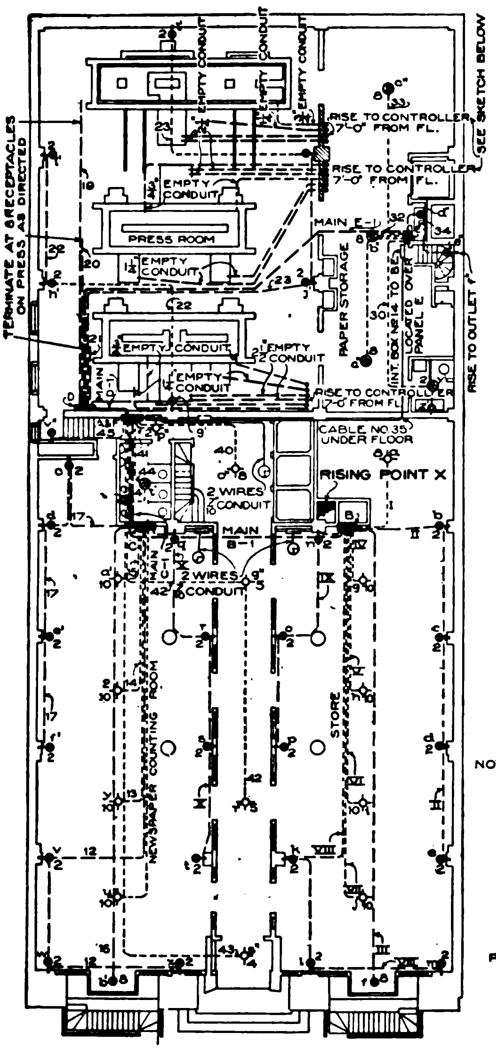
First Floor. The rear portion of the building from the basement through the first floor, Fig. 43, and including the mezzanine floor, between the first and second floors, at the rear portion of the building only, is utilized as a press room for several large and heavy, modern newspaper presses. The motors and controllers for these presses are located on the first floor. A separate feeder for each of these press motors is run directly from the main switchboard to the motor controller in each case. Empty conduits were provided, extending from the controllers to the motor in each case, intended for the various control wires installed by the contractor for the press equipments.

One-half of the front portion of the first floor is utilized as a newspaper office; the remaining half, as a bank.

Second Floor. The rear portion of the second floor, Fig. 44, is occupied as a composing and linotype room, and is illuminated chiefly by means of drop-cords from outlets located over the linotype machines and over the compositors' cases. Separate ⅛-horse-power motors are provided for each linotype machine, the circuits for the same being run underneath the floor.

Upper Floors. A typical plan (Fig. 45) is shown of the upper floors, as they are similar in all respects with the exception of certain changes in partitions, which are not material for the purpose of illustration or for practical example. The circuit work is sufficiently intelligible from the plan to require no further explanation.

Interconnection System. Fig. 46 is a diagram of the interconnection system, showing the main interconnection box located in the



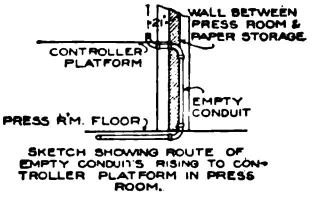
NOTE: ALL CONDUITS FOR THE PRESSES MUST COME THROUGH THE CONTROLLER PLATFORM 21" FROM THE WALL.

ALL CONDUITS ARE TO TERMINATE IN PRESS AS DIRECTED.

SCHEDULE OF CIRCUITS

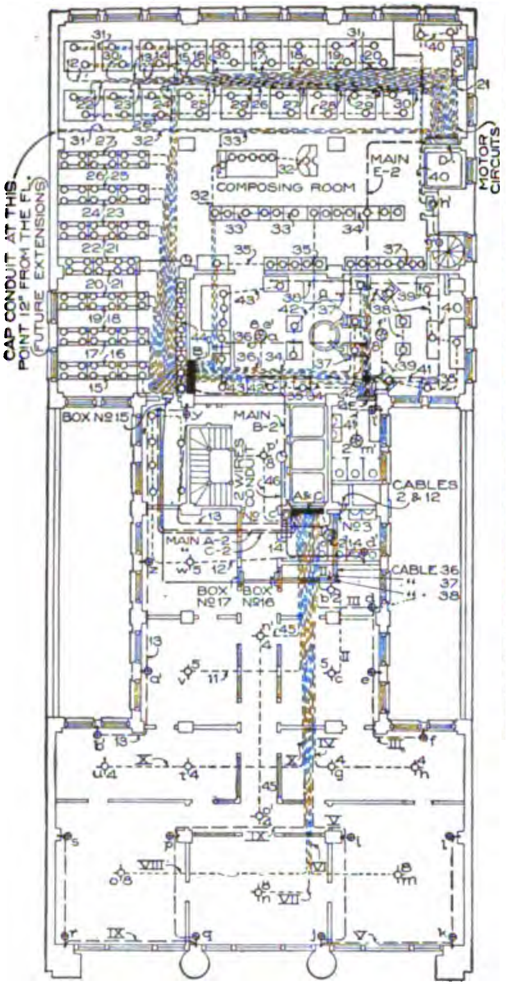
NO.	SUPPLIED		No. of BRANCHES	OUTLETS SUPPLIED	TOTAL		AT WHAT POINT CONTROLLED
	by CUTOUT	by MAIN			OUTLETS	LIGHTS	
I	B	N°2	1	a	1	8	S at B
II	"	"	1	bcde	4	8	" " "
III	"	"	1	f	1	8	" " "
IV	"	"	1	g	1	10	" " "
V	"	"	1	h	1	10	" " "
VI	"	"	1	i	1	10	" " "
VII	"	"	1	j	1	10	" " "
VIII	"	"	1	klm	3	6	" " "
IX	"	"	1	nop	3	6	" " "
			1		16	76	
X	C	C-1	1	qrst	4	8	S at C
11	"	"	1	u	1	10	" " "
12	"	"	1	vwx	3	6	" " "
13	"	"	1	y	1	10	" " "
14	"	"	1	z	1	10	" " "
15	"	"	1	a'	1	10	" " "
16	"	"	1	b'	1	8	" " "
17	"	"	1	c'd'e'f'	4	8	" " "
					16	70	
19	D	D-1	1	8 Receptacles	8	8	
20	"	"	1		8	8	
21	"	"	1		8	8	
22	"	"	1	g'h'i'	3	6	S at D
23	"	"	1	j'k'l'	3	6	" " "
24	SEE MEZZ. PLAN						
25							
26							
27							
28							
29							
30	E	E-1	1	y'z'	2	3	S at E
31	"	"	1	a"	1	8	" " "
32	"	"	1	b"	1	8	" " "
33	"	"	1	c"	1	8	" " "
34	"	"	1	d"e"f") g"/	4	4	" " "
35	SEE MEZZ. PLAN						
36							
37							
38							
39							
40	F		1	o"	1	8	S at F
41	"	"	1	p"	1	2	" " "
42	"	"	1	q"r"	2	10	" " "
43	"	"	1	s"	1	4	" " "
44	"	"	1	t"u"	2	6	" " "
45	"	"	1	v"	1	1	" " "
					8	31	" " "

NOTE: THE CLOCKS IN STORE AND COUNTING ROOM ARE TO BE LOCATED AS DIRECTED BY ARCHITECT.



SKETCH SHOWING ROUTE OF EMPTY CONDUITS RISING TO CONTROLLER PLATFORM IN PRESS ROOM.

Fig. 43. Wiring of an Office Building.
First-Floor Plan, Showing Press Room in Rear, Containing Motors and Controllers for Newspaper Presses, Fed Directly from Main Switchboard in Basement; also, in front, Newspaper Counting Room and Bank Offices.



SCHEDULE OF CIRCUITS

NO.	SUP-PLIED		No. of BRANCHES	OUTLETS SUPPLIED	TOTAL		AT WHAT POINT CONTROLLED
	by CUTOUT	by MAIN			OUTLETS	LIGHTS	
I	A	A-2	1	a	1	2	S at A
II	"	"	1	b c	2	7	
III	"	"	1	d e f	3	3	
IV	"	"	1	g h	2	8	
V	"	"	1	i j k l	4	4	
VI	"	"	1	m	1	8	
VII	"	"	1	n	"	"	
VIII	"	"	1	o	"	"	
IX	"	"	1	p q r s	4	4	
X	"	"	1	t u	2	8	
11	"	"	1	v	1	5	
12	"	"	1	w & 6 Drop Cds	7	11	
13	"	"	1	y z a' b'	4	4	
14	"	"	1	c' d'	2	2	
					30	78	
15	B	B-2	1	Drop Cords	6	6	
16	"	"	1	" "	"	"	
17	"	"	1	" "	"	"	
18	"	"	1	" "	"	"	
19	"	"	1	" "	"	"	
20	"	"	1	" "	"	"	
21	"	"	1	" "	10	10	
22	"	"	1	" "	6	6	
23	"	"	1	" "	"	"	
24	"	"	1	" "	"	"	
25	"	"	1	" "	"	"	
26	"	"	1	" "	"	"	
27	"	"	1	" "	"	"	
28	"	"	1	" "	9	9	
29	"	"	1	" "	"	"	
30	"	"	1	" "	"	"	
31	"	"	1	" "	"	"	
32	"	"	1	" "	7	7	
33	"	"	1	" "	6	6	
34	"	"	1	" "	7	7	
35	"	"	1	" "	6	6	
36	"	"	1	e'	1	8	S at B
37	"	"	1	Drop Cords	7	7	
38	"	"	1	" "	9	9	
39	"	"	1	f'	1	8	S at B
40	"	"	1	g' h' i' j' k'	5	5	
41	"	"	1	l' m'	2	3	S at B
42	"	"	1	Drop Cords	7	7	
43	"	"	1	" "	7	7	
44	"	"	1	" "	8	8	
45	C	C-2	1	n' o'	2	8	S at C'
46	"	"	1	p'	1	8	" " "

TERMINATE ALL MOTOR CIRCUITS AT MOTOR CONTROLLER AS DIRECTED

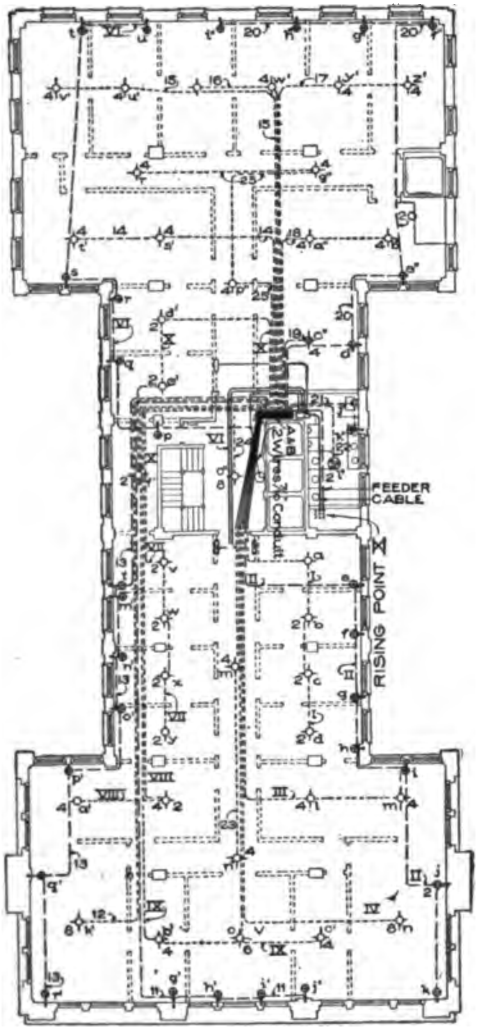
MOTOR CIRCUITS

NO.	SUPPLIED BY			H.P. SUPPLIED	CURRENT IN AMPERES	LENGTH IN FT. (ONE WAY)	SIZE OF WIRE	INSIDE DIA. OF CONDUIT ALLOWED *
	FEEDER Nº	CUT-OUT	FLOOR					
12	9	D	2ND	* *		98	10	¾"
13	"	"	"	"		90	"	"
14	"	"	"	"		82	"	"
15	"	"	"	"		76	"	"
16	"	"	"	"		68	"	"
17	"	"	"	"		60	"	"
18	"	"	"	"		52	"	"
19	"	"	"	"		46	"	"
20	"	"	"	"		38	"	"
21	"	"	"	"		28	"	"
22	"	"	"	"		94	"	"
23	"	"	"	"		86	"	"
24	"	"	"	"		78	"	"
25	"	"	"	"		70	"	"
26	"	"	"	"		62	"	"
27	"	"	"	"		54	"	"
28	"	"	"	"		46	"	"
29	"	"	"	"		38	"	"
30	"	"	"	"		30	"	"
31	"	"	"	"		90	"	"
32	"	"	"	"		"	"	"
33	"	"	"	$\frac{1}{4}$		82	"	"
34	"	E	"	3		28	"	"
35	"	"	"	"		32	"	"
36	"	"	"	"		52	"	"
37	"	"	"	"		34	"	"
38	"	"	"	1		48	12	"
39	"	"	"	2		46	10	"
40	"	"	"	3		30	"	"
41	"	"	"	2		28	"	"
42	"	"	"	3		18	"	"

* BOTH CONDUCTORS IN ONE CONDUIT

** $\frac{1}{2}$ H.P. REDUCED TO $\frac{1}{4}$ H.P.

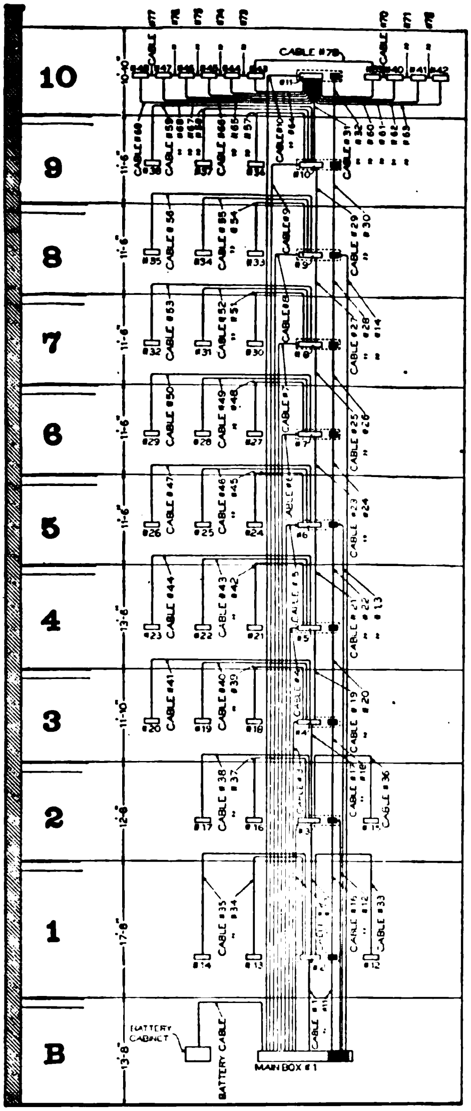
Fig. 44. Wiring of an Office Building. Plan of Second Floor. Rear Portion Occupied as a Composing and Linotype Room.



SCHEDULE OF CIRCUITS

NO.	SUPPLIED by CUTOUT	SUPPLIED by MAIN	NO. of BRANCHES	OUTLETS SUPPLIED	TOTAL OUTLETS	TOTAL LIGHTS	AT WHAT POINT CONTROLLED
I	A		1	abcd	4	8	
II	"	"	1	efghijk	7	7	
III	"	"	1	lm	2	8	
IV	"	"	1	n	1	8	
V	"	"	1	o	1	6	
VI	"	"	1	pqrstu	6	6	
VII	"	"	1	vwxy	4	8	
VIII	"	"	1	z a'	2	8	
IX	"	"	1	b'c'	2	8	
X	"	"	1	d'e'f'	3	6	
11	"	"	1	g'h'i'j'	4	4	
12	"	"	1	k'	1	8	
13	"	"	1	l'm'n'o'p'q'r'	7	7	
14	"	"	1	s't'	2	8	
15	"	"	1	u'v'	2	8	
16	"	"	1	w'x'	2	6	
17	"	"	1	y'z'	2	8	
18	"	"	1	a"b"	2	8	
19	"	"	1	c"	1	4	
20	"	"	1	d"e"f"g"h"i"	6	6	
21	"	"	1	j"k"	2	2	
22	"	"	1	l"	1	2	S at A
					64	146	
23	B		1	m"n"	2	8	S at B
24	"	"	1	o"	1	8	S " "
25	"	"	1	p"q"r"	3	12	S " "
					6	28	

Fig. 45. Wiring of an Office Building.
Typical Plan of Upper Floors, Showing Circuit Work, Schedule, etc. All the Floors above the Second are Similar to One Another in Plan, Differing Only in Comparatively Unimportant Details of Partitions.



— CABLES.—

NO.	START AT BOX NO.	START AT FLOOR	END AT BOX NO.	END AT FLOOR	NO. OF WIRES	LENGTH IN FEET	INSIDE DIA. OF CONDUIT ALLOWED
1	1	BASM'T	2	1 ST	50	122	1½"
2	"	"	3	2 ND	"	116	"
3	"	"	4	3 RD	"	129	"
4	"	"	5	4 TH	"	[illegible]	"
5	"	"	6	5 TH	"	154	"
6	"	"	7	6 TH	"	165	"
7	"	"	8	7 TH	"	176	"
8	"	"	9	8 TH	"	187	"
9	"	"	10	9 TH	"	208	"
10	"	"	11	10 TH	"	219	"
11	"	"	2	1 ST	10	122	[illegible]
12	"	"	3	2 ND	"	116	"
13	"	"	6	5 TH	"	154	"
14	"	"	9	8 TH	"	187	"
15	2	1 ST	3	2 ND	"	22	1"
16	"	"	"	"	"	"	1½"
17	3	2 ND	4	3 RD	"	16	1"
18	"	"	"	"	"	"	1½"
19	4	3 RD	5	4 TH	"	15	1"
20	"	"	"	"	"	"	1½"
21	5	4 TH	6	5 TH	"	"	1"
22	"	"	"	"	"	"	1½"
23	6	5 TH	7	6 TH	"	"	1"
24	"	"	"	"	"	"	1½"
25	7	6 TH	8	7 TH	"	"	1"
26	"	"	"	"	"	"	1½"
27	8	7 TH	9	8 TH	"	"	1"
28	"	"	"	"	"	"	1½"
29	9	8 TH	10	9 TH	"	"	1"
30	"	"	"	"	"	"	1½"
31	10	9 TH	11	10 TH	"	"	1"
32	"	"	"	"	"	"	1½"
33	2	1 ST	12	1 ST	"	61	1"
34	"	"	13	"	"	[illegible]	"
35	"	"	14	"	"	[illegible]	"
36	3	2 ND	15	2 ND	"	[illegible]	"
37	"	"	16	"	"	[illegible]	"
38	"	"	17	"	"	[illegible]	"
39	4	3 RD	18	3 RD	"	[illegible]	"
40	"	"	19	"	"	[illegible]	"
41	"	"	20	"	"	[illegible]	"
42	5	4 TH	21	4 TH	"	[illegible]	"
43	"	"	22	"	"	[illegible]	"
44	"	"	23	"	"	[illegible]	"
45	6	5 TH	24	5 TH	"	[illegible]	"
46	"	"	25	"	25	[illegible]	1½"
47	"	"	26	"	10	[illegible]	1"
48	7	6 TH	27	6 TH	"	[illegible]	"
49	"	"	28	"	"	[illegible]	"
50	"	"	29	"	"	[illegible]	"
51	8	7 TH	30	7 TH	"	[illegible]	"
52	"	"	31	"	"	[illegible]	"
53	"	"	32	"	"	[illegible]	"
54	9	8 TH	33	8 TH	"	[illegible]	"
55	"	"	34	"	"	[illegible]	"
56	"	"	35	"	"	[illegible]	"
57	10	9 TH	36	9 TH	"	[illegible]	"
58	"	"	37	"	"	[illegible]	"
59	"	"	38	"	"	[illegible]	"
60	11	10 TH	39	10 TH	"	[illegible]	"
61	"	"	40	"	"	[illegible]	"
62	"	"	41	"	"	[illegible]	"
63	"	"	42	"	"	[illegible]	"
64	"	"	43	"	"	[illegible]	"
65	"	"	44	"	"	[illegible]	"
66	"	"	45	"	"	[illegible]	"
67	"	"	46	"	"	[illegible]	"
68	"	"	47	"	"	[illegible]	"
69	"	"	48	"	"	[illegible]	"
70	[illegible]	"	[illegible]	"	*	[illegible]	"
71	[illegible]	"	41	"	"	[illegible]	"
72	41	"	[illegible]	"	"	[illegible]	"
73	[illegible]	"	[illegible]	"	"	[illegible]	"
74	44	"	[illegible]	"	"	[illegible]	"
75	45	"	46	"	"	"	"
76	46	"	[illegible]	"	"	"	"
77	47	"	48	"	"	"	"
78	[illegible]	"	[illegible]	"	"	"	"

* EMPTY CONDUIT ONLY

— BOXES.—

NO.	FLOOR	NO. REQUIRED OF VARIOUS SIZES: 60 F	1-A	14-B	16-B	20-B	2-B	2-A				
1	BASM'T	1										
2	1 ST			1								
3	2 ND				1							
4	3 RD			1								
5	4 TH			1								
6	5 TH				1							
7	6 TH			1								
8	7 TH			1								
9	8 TH				1							
10	9 TH			1								
11	10 TH					1						
12	1 ST						1					
13	"						1					
14	"						1					
15	2 ND						1					
16	"						1					
17	"						1					
18	3 RD						1					
19	"						1					
20	"						1					
21	4 TH						1					
22	"						1					
23	"						1					
24	5 TH						1					
25	"						1					
26	"						1					
27	6 TH						1					
28	"						1					
29	"						1					
30	7 TH						1					
31	"						1					
32	"						1					
33	8 TH						1					
34	"						1					
35	"						1					
36	9 TH						1					
37	"						1					
38	"						1					
39	10 TH		1									
40	"		1									
41	"		1									
42	"		1									
43	"		1									
44	"		1									
45	"		1									
46	"							1				
47	"		1									
48	"		1									
TOTALS		1	9	6	3	1	27	1				

— FIXTURES. —

LOCATION	BATTERIES	BATTERY CABINET	CLOCKS	MASTER CLOCK								
BASEMENT	28	1										
1 ST FL.			4									
2 ND "			2									
3 RD "			1									
4 TH "			1									
5 TH "			1									
6 TH "			1									
7 TH "			1									
8 TH "			1									
9 TH "			1									
10 TH "			3	1								
TOTALS	28	1	16	1								

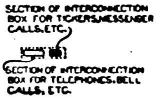

SECTION OF INTERCONNECTION BOX FOR TICKERS, MESSENGER CALLS, ETC.
SECTION OF INTERCONNECTION BOX FOR TELEPHONES, BELL CALLS, ETC.

Fig. 46. Wiring of an Office Building. Diagram of the Interconnection System.

basement; adjoining this main box is located the terminal box of the local telephone company. A separate system of feeders is provided for the ticker system, as these conductors require somewhat heavier insulation, and it was thought inadvisable to place them in the same conduits with the telephone wires, owing to the higher potential of ticker circuits. A separate interconnection cable runs to each floor, for telephone and messenger call purposes; and a central box is placed near the rising point at each floor, from which run subsidiary cables to several points symmetrically located on the various floors. From these subsidiary boxes, wires can be run to the various offices requiring telephone or other service. Small pipes are provided to serve as raceways from office to office, so as to avoid cutting partitions. In this way, wires can be quickly provided for any office in the building without damaging the building in any way whatever; and, as provision is made for a special wooden moulding near the ceiling to accommodate these wires, they can be run around the room without disfiguring the walls. All the main cables and subsidiary wires are connected with special interconnection blocks numbered serially; and a schedule is provided in the main interconnection box in the basement, which enables any wire originating thereat, to be readily and conveniently traced throughout the building. All the main cables and subsidiary cables are run in iron conduits.

OUTLET-BOXES, CUT-OUT PANELS, AND OTHER ACCESSORIES

Outlet-Boxes. Before the introduction of iron conduits, outlet-boxes were considered unnecessary, and with a few exceptions were not used, the conduits being brought to the outlet and cut off after the walls and ceilings were plastered. With the introduction of iron conduits, however, the necessity for outlet-boxes was realized; and the *Rules* of the Fire Underwriters were modified so as to require their use. The *Rules of the National Electric Code* now require outlet-boxes to be used with rigid iron and flexible steel conduits, and with armored cables. A portion of the rule requiring their use is as follows:

> All interior conduits and armored cables "must be equipped at every outlet with an approved outlet-box or plate.
>
> "Outlet-plates must not be used where it is practicable to install outlet-boxes.

"In buildings already constructed, where the conditions are such that neither outlet-box nor plate can be installed, these appliances may be omitted by special permission of the inspection department having jurisdiction, providing the conduit ends are bushed and secured."

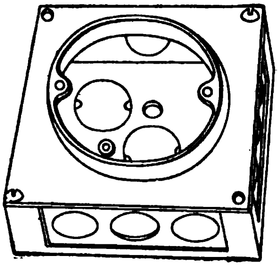


Fig. 47. Universal and Knock-Out Type of Outlet Box.

Fig. 47 shows a typical form of outlet-box for bracket or ceiling outlets of the *universal type.* When it is desired to make an opening for the conduits, a blow from a hammer will remove any of the weakened portion of the wall of the outlet-box, as may be required. This form of outlet-box is frequently referred to as the *knock-out type.* Other forms of outlet-boxes are made with the openings cast in the box at the required points, this class being usually stronger and better made than the universal type. The advantages of the universal type of outlet-box are that one form of box will serve for any ordinary conditions, the openings being made according to the number of conduits and the directions in which they enter the box.

Fig. 48 shows a waterproof form of outlet-box used out of doors, or in other places where the conditions require the use of a water-tight and waterproof outlet-box.

It will be seen in this case, that the box is threaded for the conduits, and that the cover is screwed on tightly and a flange provided for a rubber gasket.

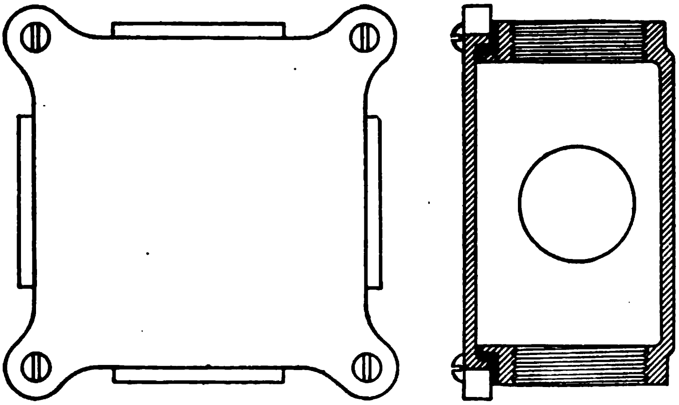


Fig. 48. Water-Tight Outlet Box.
Courtesy of H. Krantz Manufacturing Co., Brooklyn, N. Y.

Figs. 49 and 50 show water-tight floor boxes which are for outlets located in the floor. While the rules do not require that the floor outlet-box shall be water-tight, it is strongly recommended that a water-tight outlet be used in all cases for floor connections. In this case also, the conduit opening is threaded, as well as the stem cover through which the extension is made in the conduit to the desk or table. When the floor outlet connection is not required, the stem cover may be removed and a flat, blank cover be used to replace the same.

A form of outlet-box used for flexible steel cables and steel armored cable, has already been shown (see Fig. 5).

There is hardly any limit to the number and variety of makes of outlet-boxes on the market, adapted for ordinary and for special conditions; but the types illustrated in these pages are characteristic and typical forms.

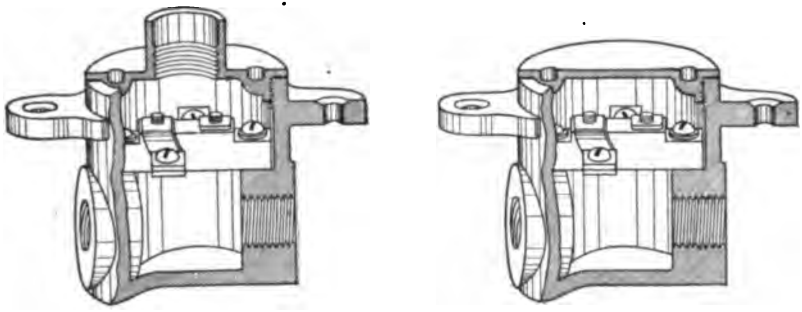


Fig. 49. Fig. 50.

Types of Floor Outlet-Boxes.

Bushings. The *Rules of the National Electric Code* require that conduits entering junction-boxes, outlet-boxes, or cut-out cabinets, shall be provided with approved *bushings,* fitted to protect the wire from abrasion.

Fig. 51 shows a typical form of conduit bushing. This bushing is screwed on the end of the conduit after the latter has been introduced into the outlet-box, cut-out cabinet, etc., thereby forming an insulated orifice to protect the wire at the point where it leaves the conduits, and to prevent abrasion, grounds, short circuits, etc. A lock-nut (Fig. 52) is screwed on the threaded end of the conduit before the conduit is placed in the outlet-box or cut-out cabinet, and this lock-nut and bushing clamp the conduit securely in position. Fig.

53 shows a terminal bushing for panel-boxes used for flexible steel conduit or armored cable.

The *Rules of the National Electric Code* require that the metal of conduits shall be permanently and effectually grounded, so as to insure a positive connection for grounds or leaking currents, and in order to provide a path of least resistance to prevent the current from finding a path through any source which might cause a fire. At outlet-boxes, the conduits and gaspipes must be fastened in such a manner as to insure good electrical connection; and at centers of distribution, the conduits should be joined by suitable bond wires, preferably of copper, the said bond wires being connected to the metal structure of the building, or, in case of a building not having an iron or steel structure, being grounded in a permanent manner to water or gas piping.

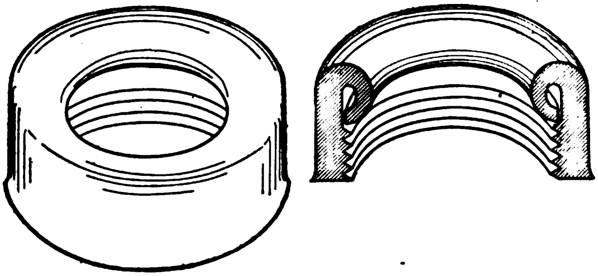


Fig. 51. Conduit Bushing.

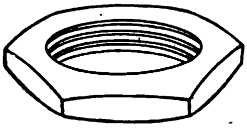


Fig. 52. Lock-Nut.

Fuse-Boxes, Cut-Out Panels, etc. From the very outset, the necessity was apparent of having a protective device in circuit with the conductor to protect it from overload, short circuits, etc. For this purpose, a fusible metal having a low melting point was employed. The form of this fuse has varied greatly. Fig. 54 shows a characteristic form of what is known as the *link fuse* with copper terminals, on which are stamped the capacity of the fuse.

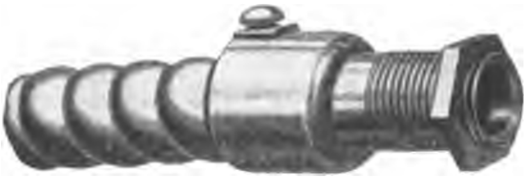


Fig. 53. Panel-Box Terminal Bushing.
Courtesy of Sprague Electric Co., New York, N. Y.

The form of fuse used probably to a greater extent than any other, although it is now being superseded by other more modern forms, is that known as the *Edison fuse-plug,* shown in Fig. 55. A porcelain *cut-out block* used with the Edison fuse is shown in Fig. 56.

Within the last four or five years, a new form of fuse, known as the *enclosed fuse,* has been introduced and used to a considerable extent. A fuse of this type is shown in Fig. 57. Fig. 58 gives a sectional view of this fuse, showing the porous filling surrounding the fuse-strips, and also the device for indicating when the fuse has blown. This form of fuse is made with various kinds of terminals; it can be used with spring clips in small sizes, and with a post screw contact in larger sizes. For ordinary low potentials this fuse is desirable for currents up to 25 amperes; but it is a debatable question whether it is desirable to use an enclosed fuse for heavier currents. Fig. 59 shows a *cut-out box* with Edison plug fuse-blocks used with knob and tube wiring. It will be seen that there is no connection compartment in this fuse-box, as the circuits enter directly opposite the terminals with which they connect.

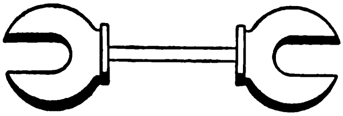


Fig. 54. Copper-Tipped Fuse Link.

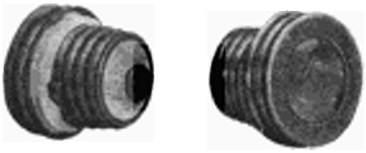


Fig. 55. Edison Fuse-Plug.
Courtesy of General Electric Co., Schenectady, N. Y.

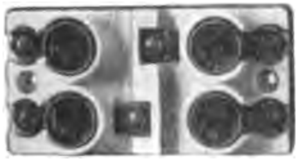


Fig. 56. Porcelain Cut-Out Block.
Courtesy of General Electric Co., Schenectady, N. Y.

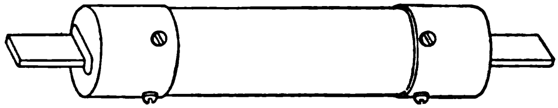


Fig. 57. Enclosed or "Cartridge" Fuse.

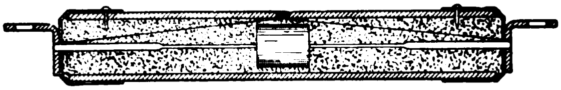


Fig. 58. Section of Enclosed Fuse.

Fig. 60 shows a *cut-out panel* adapted for enclosed fuses, and installed in a cabinet having a connection compartment. As will be seen from the cut, the tablet itself is surrounded on the four sides by slate, which is secured in the corners by angle-irons. The outer box may be of wood lined with sheet iron, or it may be of iron. Fig. 61 shows a door and trim for a cabinet of this type. It will be seen that the door opens only on the center panel, and that the trim covers and conceals the connection compartment. The inner side of the door should be lined with slate, and the inner side of the trim should be lined with sheet iron. Fig. 62 shows a sectional view of the cabinet and panel. In this type of cabinet, the conduits may enter at any point, the wires being run to the proper connectors in the connection compartment.

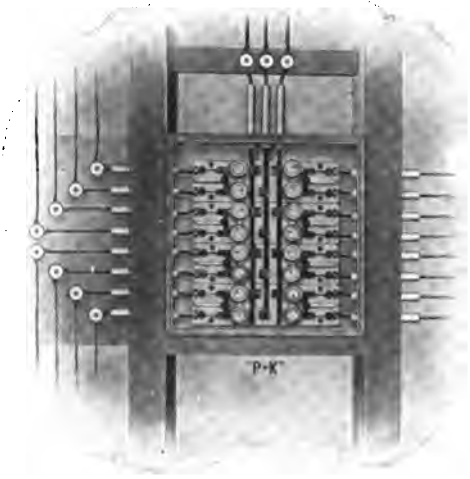


Fig. 59. Porcelain Cut-Outs in Wooden Box.
Courtesy of H. T. Paiste Co., Philadelphia, Pa.

Figs. 63 and 64 illustrate a type of panelboard and cabinet having a push-button switch connected with each branch circuit and so arranged that the cut-out panel itself may be enclosed by locked doors, and access to the switches may be obtained through two separate doors provided with latches only. This type of panel was arranged and designed by the author of this instruction paper.

OVERHEAD LINEWORK

The advantages of overhead linework as compared with underground linework are that it is much less expensive; it is more readily and more quickly installed; and it can be more readily inspected and repaired.

Its principal disadvantages are that it is not so permanent as underground linework; it is more easily deranged; and it is more unsightly.

For large cities, and in congested districts, overhead linework should not be used. However, the question of first cost, the question of permanence, and the municipal regulations, are usually the factors which determine whether overhead or underground linework shall be used.

The principal factors to be considered in overhead linework will be briefly outlined.

Placing of Poles. As a general rule, the poles should be set from 100 to 125 feet apart, which is equivalent to 53 to 42 poles per mile. Under certain conditions, these spacings given will have to be modified; but if the poles are spaced too far apart, there is danger of too great a strain on the poles themselves, and on the cross-arms, pins, and conductors. If, on the other hand, they are placed too close together, the cost is unnecessarily increased. The size and number of conductors, and the potential of the linework, determine to a great extent the distance between the poles; the smaller the size, the less the number of conductors; and the lower the potential, the greater the distance between the poles may be made. Of course, the exact location of the poles is subject to variation because of trees, buildings, or other obstructions. The usual method employed in locating poles, is first to make a map on a fairly large scale, showing the course of the linework, and then to locate the poles on the ground according tc the actual conditions.

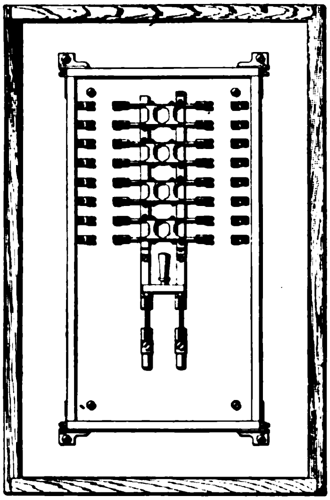


Fig. 60. Plan View, Cover, and Section of Double Cut-Out Box.

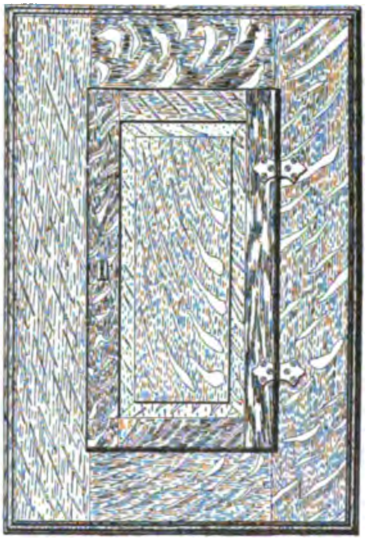


Fig. 61.

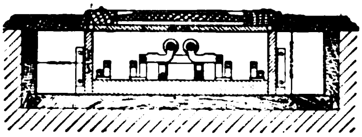


Fig. 62.

Poles. Poles should be of selected quality of chestnut or cedar, and should be sound and free from cracks, knots, or other flaws. Experience has proven that chestnut and cedar poles are the most durable and best fitted for linework. If neither chestnut nor cedar poles can be obtained, northern pine may be used, and even other timber in localities where these poles cannot be obtained; but it is found that the other woods do not last so long as those mentioned, and some of the other woods are not only less strong initially, but are apt to rot much quicker at the "wind and water line"—that is, just above and below the surface of the ground.

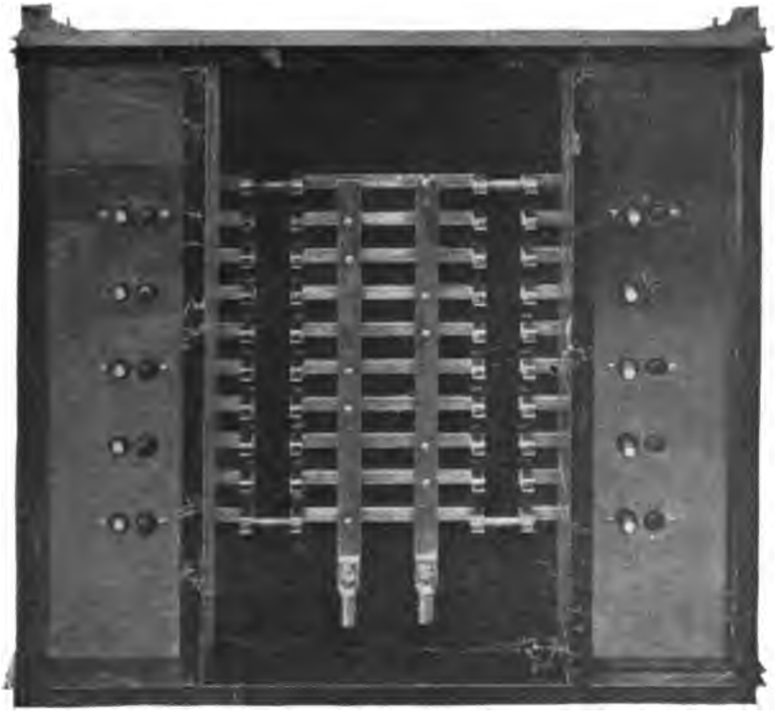
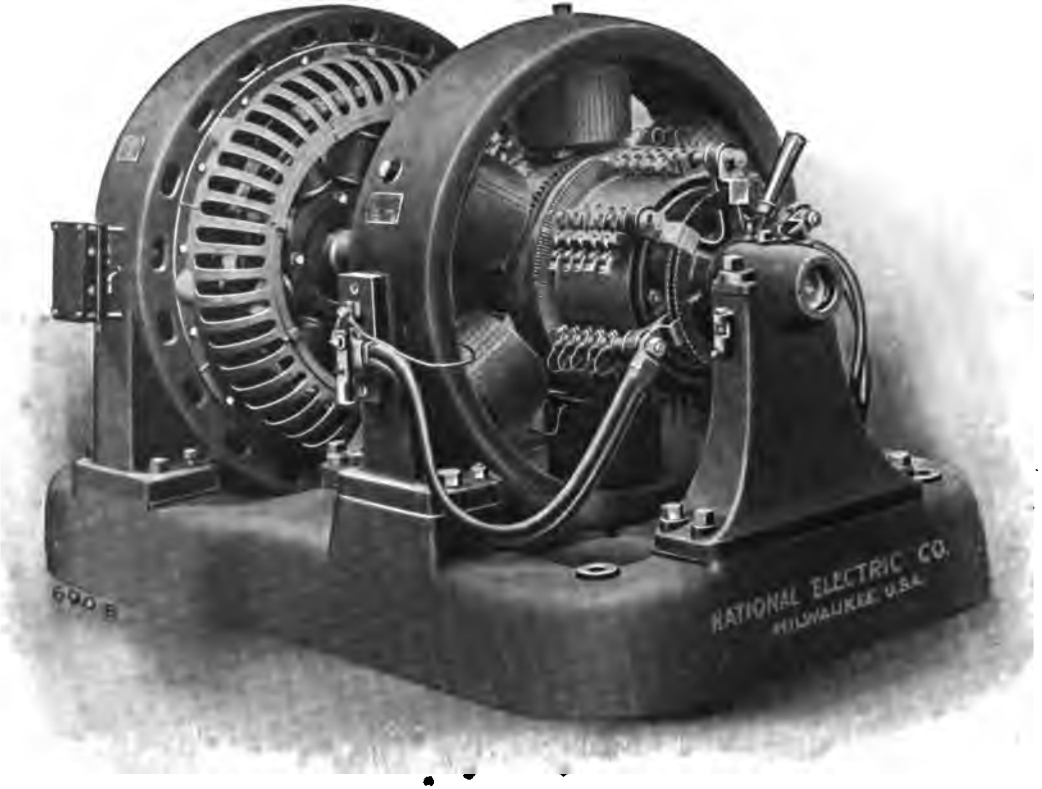


Fig. 63. Cut-Out Panel with Push-Button Switches. Cover Removed.

The proper height of pole to be used depends upon conditions. In country and suburban districts, a pole of 25 to 30 feet is usually of sufficient height, unless there are more than two or three cross-arms required. In more densely populated districts and in cities where a great number of cross-arms are required, the poles may have to be



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40 to 60 feet, or even longer. Of course, the longer the pole, the greater the possibility of its breaking or bending; and as the length increases, the diameter of the butt end of pole should also increase. Table X gives the average diameters required for various heights of poles, and the depth the poles should be placed in the ground. These data have been compiled from a number of standard specifications.

TABLE X
Pole Data

LENGTH OF POLE	DIAMETER 6 IN. FROM BUTT	DIAMETER AT TOP	DEPTH POLE SHOULD BE PLACED IN GROUND
25 feet	9 to 10 in.	6 to 8 in.	5 feet
30 "	11 "	"	5½ "
35 "	12 "	"	5½ "
40 "	13 "	"	6 "
45 "	14 "	"	6½ "
50 "	15 "	"	7 "
55 "	16 to 17 "	"	7½ "
60 "	18 "	"	7½ "
65 "	19 "	"	8 "
70 "	20 "	"	8 "
75 "	21 "	"	8½ "
80 "	22 "	"	9 "

As it is somewhat difficult, because of irregularities in size, to measure the diameter of some poles, the circumference may be measured instead; then, by multiplying the diameters given in the above table, by 3,1416, the measurements may be reduced to the circumference in inches.

The minimum diameters of the pole at the top, which should be allowed, will depend largely on the size of the conductors used, and on the potential carried by the circuits; the larger the conductors and the higher the potentials, the greater should be the diameter at the top of the pole.

Poles should be shaved, housed, and gained, also cleaned and ready for painting, before erection.

Poles should usually be painted, not only for the sake of appearance, but also in order to preserve them from the weather. It is particularly important that they should be protected at their butt end, not only where they are surrounded by the ground, but for a foot or two above the ground, as it is at this point that poles usually deteriorate most rapidly. Painting is not so satisfactory at this point as the use of tar, pitch, or creosote. The life of the pole can be increased considerably by treating it with one or another of these preservatives.

Before any poles are erected, they should be closely inspected for flaws and for crookedness or too great departure from a straight line.

Where appearance is of considerable importance, octagonal poles may be used, although these cost considerably more than round poles. *Gains* or notches for the cross-arms should be cut in the poles before they are erected, and should be cut square with the axis of the pole, and so that the cross-arms will fit snugly and tightly within the space thus provided. These gains should be not less than 4½ inches wide, nor less than ½ inch deep. Gains should not be placed closer than 24 inches between centers, and the top gains should be at least 9 inches from the apex of the pole.

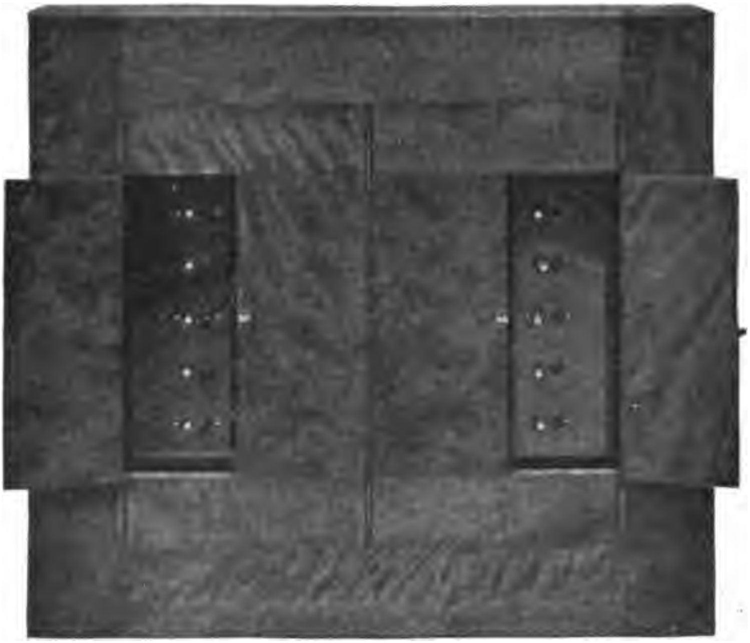

Fig. 64. Cut-Out Panel with Push-Button Switches. With Cover.

Pole Guying. Where poles are subject to peculiar strains due to unusual stress of the wires, such as at corners, etc., *guys* should be employed to counteract the strain and to prevent the pole from being bent and finally broken, or from being pulled from its proper position.

Where there are a considerable number of wires on the poles, or in case of unusually long poles, or where the linework is subject to severe storms, it is frequently necessary to guy the poles even on straight linework. In such cases, the guys should extend from a point near the top of the pole to a point near the butt of the adjacent pole. Straight guying should also be employed at the terminal pole, the guy extending to a stub beyond the last pole, to counteract the strain of the wires pulling in the opposite direction. On particularly heavy lines, it is sometimes necessary to use straight guys for the second and even the third pole from the terminal pole, to prevent undue strain on the terminal pole itself, as shown in Fig. 65.

Where there are three or more cross-arms, either two sets of guys should be employed, or else a "Y" form of guy should be used. If a single guy is used on a long pole or on a pole carrying a number of cross-arms, or on which there is unusual strain, the pole is apt to break where the guy is attached. Figs. 66 and 67 show respectively a proper and an improper method of guying, and their effect.

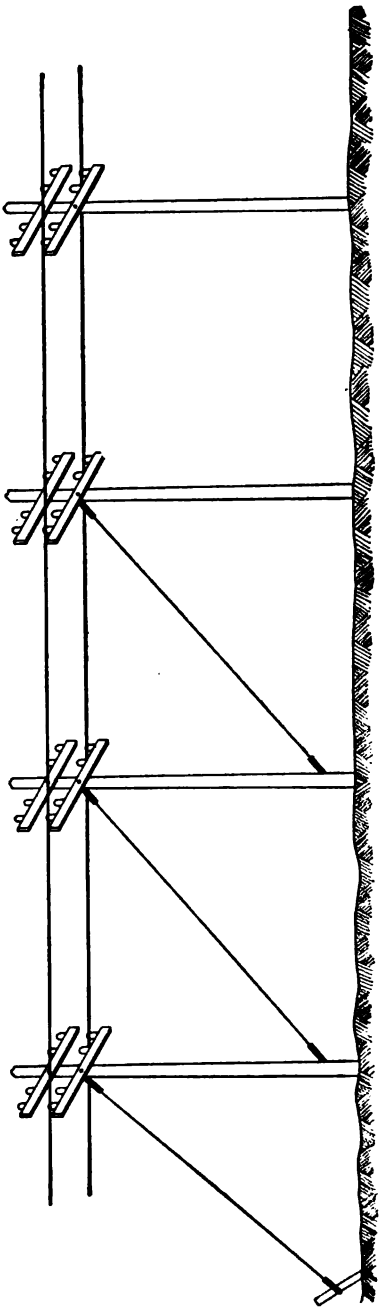

Fig. 65. Use of Straight Guys on Poles at Terminus of Heavy Line.

At corners, or wherever the direction of the linework changes, guys should be provided to counteract the strain due to the change in direction. Guys are also necessary at points where poles are set in other than a vertical position.

Where the soil is not firm or solid, or where poles are subject to unusual stress, it is sometimes necessary to obtain additional stiffness by what is known as *crib-bracing,* as may be seen from Fig. 68. This consists of placing two short logs at the butt of the pole. These logs need not be more than 4 to 5 feet long, or more than 8 to 9 inches in diameter. This crib-bracing is sometimes also necessary to give greater stability to stubs or short poles to which guys are fastened.

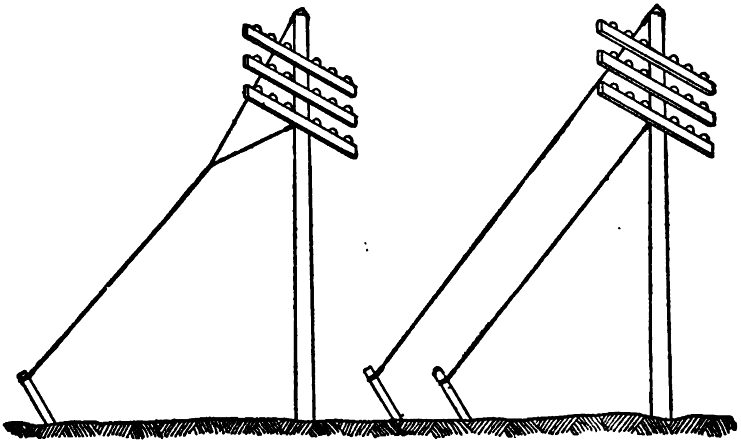

Fig. 66. Proper Method of Guying where there are Three or More Cross-Arms. A Y-form of Guy is Used at Left; Double Guy at Right.

While, as a rule, it is not advisable to use trees for guy supports, it is sometimes necessary to do this, but the trees should be sound and should be protected in a proper manner from injury. On private property, permission should first be obtained from the owner to use the tree for such purpose.

The guy itself should be of standard cable, consisting of 7 strands of No. 12 B. & S. Gauge iron or steel wire. This is the standard *guy cable,* and should be used in all cases, except for very light poles and light linework, where a smaller cable having a minimum diameter of ¼ inch may be used. The guy wires should be fastened at the ends by means of suitable clamps. All guy cables and clamps should be heavily galvanized, to prevent rusting.

Corners. In cases of heavy linework where there are a considerable number of wires and cross-arms, the turns should be made, if possible, by the use of two poles. In cases where there are only a few wires, a double cross-arm may be employed, using a single pole. The two methods are illustrated in Figs. 69 and 70.

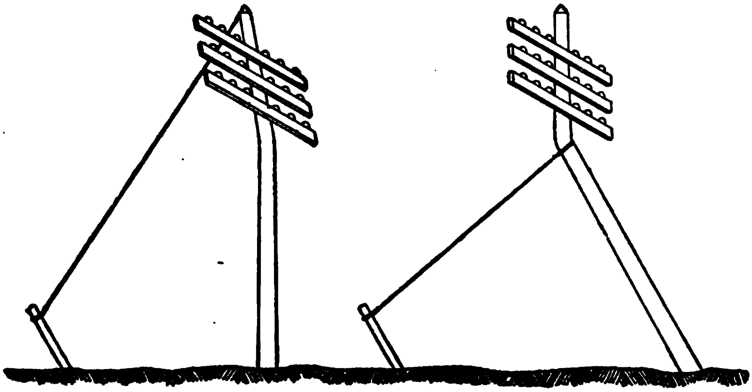

Fig. 67. Improper Method of Guying where there are Three or More Cross-Arms. Strain is Concentrated at one Point, Causing Rupture of Pole.

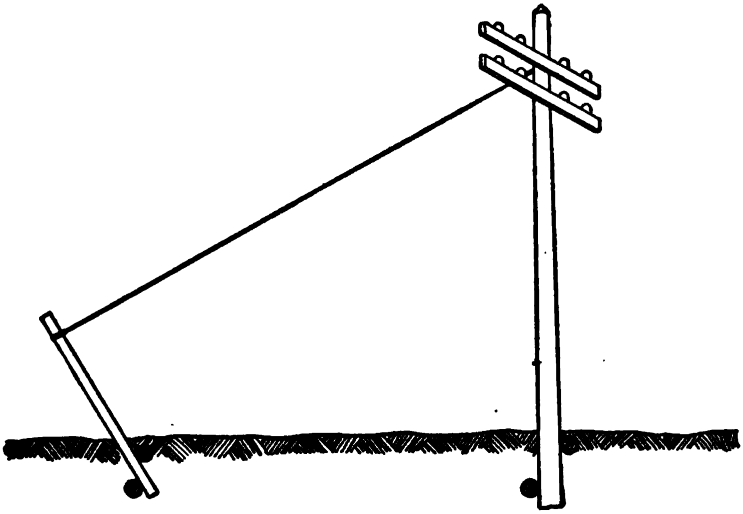

Fig. 68. Additional Stiffness Secured by Use of Crib-Bracing.

Cross-Arms. Cross-arms, where possible, should be of long leaf yellow pine, or of Oregon or Washington fir, of sound wood, thoroughly seasoned and free from sap, cracks, or large knots. They should be not less than ¾ inch thick by 4¼ inches deep, the length depending upon the number of pins required.

Cross-arms, after being properly seasoned, should be painted with two coats of lead paint before erection. They should then be snugly fitted into the gain of the pole, and securely fastened with a bolt not less than ⅝ inch in diameter driven through a hole of slightly less diameter previously bored in the pole. A galvanized-iron washer not less than 2 inches in diameter should be placed under the head and nut of each bolt. The cross-arms should be at right angles to the pole, and should be parallel to one another where two or more arms are used on the same pole.

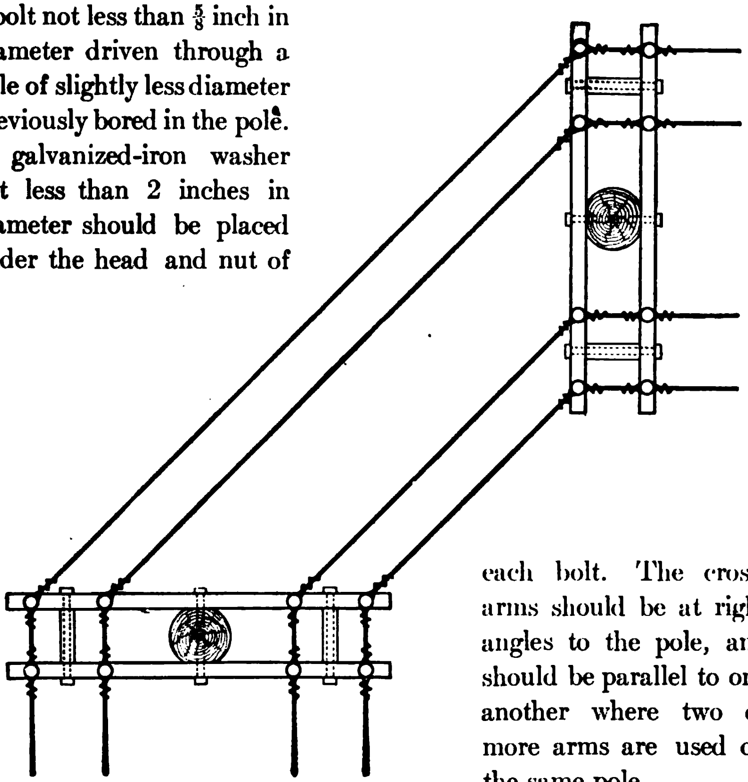

Fig. 69. Two-Poles Used in Making Turn on Heavy Line.

The cross-arms should be braced with galvanized-iron *braces* approximately 1¼ inches wide, 1¼ inches thick, and from 18 to 30 inches in length. The braces should be fastened to the cross-arm by means of ⅜-inch galvanized-iron bolts passing through the brace and the cross-arm, washers being used under the nut and head of each bolt. Guys should be provided for the cross-arms in case of unusual strain. The dimensions of cross-arms required for various numbers of pins, are given very completely in a paper read by Mr. Paul Spencer before the Atlantic City Convention of the National Electric Light Association in 1906, and reprinted in a number of the technical journals.

Wherever practicable, cross-arms should be placed on the poles before the poles are erected, as not only can they be more securely fastened when the poles are on the ground, but the cost of erection is thereby considerably reduced.

Pins. Pins should be of selected locust, not less than 1½ inches in diameter at the shank portion, and not less than ⅞ inch in diameter at the point where they rest upon the cross-arm. For potentials of 20,000 volts or over, the pins should be of metal, to avoid carbonization of the wood due to static leakage. The top portion of the pin (if of wood) should be not less than one inch in diameter. The length of both the shank and the upper portion should be each approximately 4½ inches, making the total length approximately 9 inches. The pin should be threaded and tapered, and accurately cut. The pin should fit the hole in the cross-arm snugly, and should be nailed to the cross-arm with a sixpenny galvanized-iron wire nail driven straight through the center of the shank of the pin.

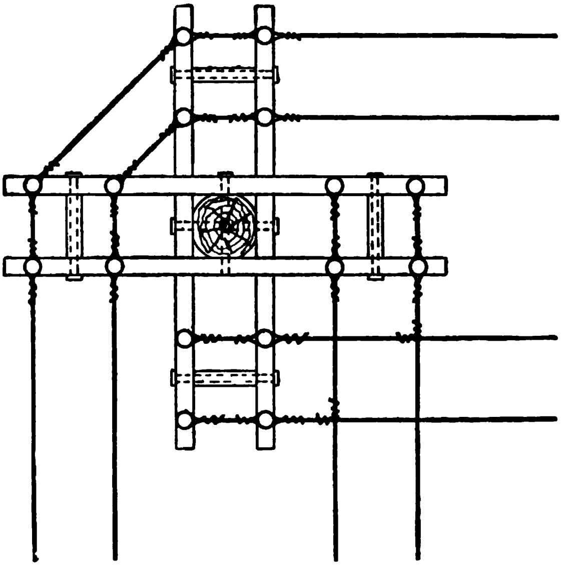

Fig. 70. Double Cross-Arm Used on Single Pole to Make Turn in Heavy Line Carrying Only a Few Wires.

Insulators. For potentials of 3,000 volts or less, insulators should be of flint glass, of double-petticoat, deep-grooved type. For potentials of over 3,000 volts, they should be of the triple-petticoat type, and preferably of porcelain, and should be of special pattern adapted for the potential.

Service Mains, Pole Wiring, etc. For service connections—

that is, for the mains run to service switches in consumers' residences or other buildings, conductors of not less than No. 8 B. & S. Gauge should be used in order to obtain the necessary tensile strength. Where possible, the circuits should be arranged in such a manner as to have the service main connect with the line on the lowest cross-arm, in order to prevent crossing of wires. The transformers should be installed either on poles or in vaults outside of the building, or, where this is impracticable, in a fireproof vault or other enclosed space inside of the building itself. Small transformers may be fastened to a pair of cross-arms secured to the pole itself. For transformers of 25 coils and over, it is usually best to provide special poles. It is inadvisable to place transformers on building walls.

Where appearance is of importance, when the transformer is placed underground, or when the wires enter the lower portion of a building, the conductors must be run underground. In such cases, a splice should be made between the weatherproof conductors and rubber-insulated lead-sheathed conductors, at a height of about 15 to 20 feet above the ground, and the mains run in iron pipe down the pole to a point underground, where they may be continued either in iron pipe or in vitrified or fiber conduits underground to the point of entrance.

All circuit wiring on poles should be so arranged as to leave one side free for the linemen to climb the poles without injuring the conductors. As a rule, all poles on which transformers, lightning arresters, or fuse-boxes are located, should be provided with steps.

In order to limit the area of disturbance of a short circuit or overload, fuses should be inserted in each leg of a primary circuit in making connections to transformers, or where tap or branch connections are made. The fuses should have a capacity of approximately 50 per cent greater than the transformer or conductor which they protect. Of course, it would be undesirable to have an excessive number of fuses, and for short branch lines they might frequently be undesirable; but for important branch lines, they should be employed in order to prevent the fuse on the main feeder from being *blown* in case of disturbance on the branch line.

Lightning arresters should be placed on the linework in places particularly exposed to lightning discharges, and at all points where connections are made to enter a building. The location and number of lightning arresters will depend upon local conditions, the likelihood and frequency of thunderstorms, etc. Where lightning arresters are provided, it is essential that a good ground connection be obtained. The ground connection should be made by a fairly good-sized insulated rubber conductor, not less than No. 6 B. & S. Gauge, connecting either with a water pipe to which it should be clamped, or fastened in such a manner as to obtain a good electric contact, or else to a ground-plate of copper embedded in crushed charcoal or coke.

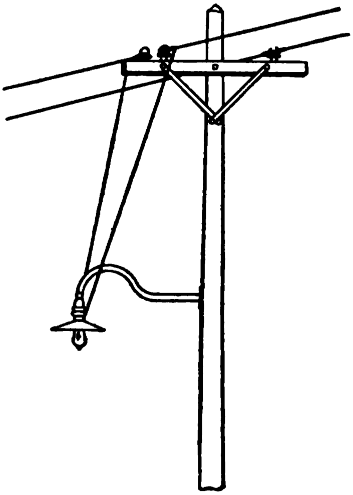
Fig. 71. Method of Wiring to and Supporting Lamp on Pole.

The neutral wire of a three-wire of both secondary alternating-current systems and direct-current systems, should be properly grounded as required by the *National Electric Code* (see Rules 12, 13, and 13-A).

Lamps on Poles. Fig. 71 shows the method of wiring to and supporting a lamp located on a pole.

UNDERGROUND LINEWORK

In large cities, or in congested districts, or where the appearance of overhead linework is objectionable, it is generally necessary to place the conductors underground instead of overhead.

The advantages of underground linework are—*first,* that of appearance; *second,* it is more permanent and less liable to interruption than overhead work.

The principal disadvantage of underground work is the greater first cost. In overhead linework, conductors having weatherproof insulators consisting of cotton dipped in a special compound similar to pitch, are used, the cost of which is relatively small. For underground linework, however, the conductors must not only have rubber insulation, but also a lead sheathing for mechanical protection.

Furthermore, the cost of the ducts, trenching, concrete work, laying the ducts, etc., is much greater than the cost of poles, cross-arms, etc.

As in the case of inside wiring, underground linework should be so arranged that the conductors may be readily removed and replaced without disturbing the underground conduits or ducts. The system should be arranged with *manholes*, and in such a manner that changes or additions or branches may be readily and conveniently made. In order to provide for the removal and replacing of conductors, and also for growth in the system, the method formerly in vogue, of embedding the conductors in wooden boxes, or in trenches underground, has been abandoned; and the conductors are now placed in *conduits* or *ducts*. A number of different forms of ducts and conduits have been introduced, some of which have been dropped as cheaper and better forms have been introduced. The forms of conduits or ducts now most generally employed include *iron pipe*, *vitrified conduits*, and *fibre conduit*. As all three of these forms of conduit are very generally employed, they will now be described, as well as the method of installing them.

Iron Pipe. Three-inch iron conduit is frequently used for underground linework, particularly for short runs or where there are not more than two or three ducts required, or where the soil is bad and where the longer lengths and more stable joints of the iron conduit would make it more desirable than vitrified duct or fibre conduit. This conduit, however, is generally undesirable on account of its greater first cost, and also on account of its liability to deterioration from rust or corrosion. Where iron conduit is used, and where it is subject to corrosion, it should be coated with asphaltum or other similar protective composition. While it is not necessary to have a concrete bed under iron pipe, it is better to provide such a bed, especially where the soil is shifting or not solid.

Vitrified Tile Conduit. This type of conduit in both the single- and multiple-duct form, is used more extensively than any other form of conduit for underground work. It is made in lengths of 18 inches for the single-duct form, and in considerably greater lengths in the multiple-duct form. Fig. 72 shows the single-duct conduit, and Fig. 73 shows a multiple-duct form of conduit.

Vitrified conduit requires less space for the same number of ducts than any other form, and is particularly desirable where a great number of ducts are required in a small space. The advantages of this form of conduit are that it is cheap in first cost; after being laid, it is practically indestructible; it is not subject to corrosion or deterioration; it is not combustible; it is fairly strong mechanically; and it does not require skilled labor to install.

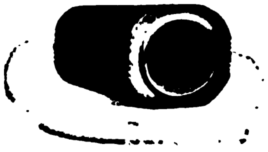

Fig. 72. Self-Centering Duct, Vitrified Conduit.
Courtesy of Standard Vitrified Conduit Co., New York, N. Y.

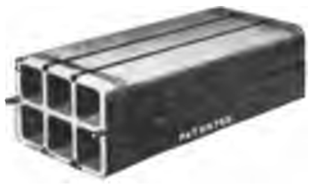

Fig. 73. Multiple Duct, Vitrified Conduit.
Courtesy of Standard Vitrified Conduit Co., New York, N. Y.

Table XI gives the principal data of one of the well-known makes of vitrified conduit.

TABLE XI

Standard Vitrified Conduit

Style of Conduit	Dimension of Square Duct (Inches)	Dimension of Round Duct (Inches)	Outside Dimensions of End Section (In.)	Reg. Stock Lengths (Inches)	Short Lengths (Inches)	Approx. Weight per Duct (Foot)
2-duct multiple...	3⅜ sq.	3¼	5 x 9	24	6, 9, 12	8 lbs.
3-duct multiple...	3⅜ sq.	3¼	5 x 13	24	6, 9, 12	8 "
4-duct multiple...	3⅜ sq.	3¼	9 x 9	36	6, 9, 12	8 "
6-duct multiple...	3⅜ sq.	3¼	9 x 13	36	6, 9, 12	8 "
9-duct multiple...	3⅜ sq.	3¼	13 x 13	36	6, 9, 12	8 "
Common single duct		3⅜	5 x 5	18	6, 9, 12	8 "
Single duct, self-centering......		3⅜	5 x 5	18	6, 9, 12	10 "
Round single duct, self-centering...		3¼	5 in. round	18	6, 9, 12	10 "

In installing vitrified conduit, a trench following as straight lines as possible should be dug to such a depth that there will be a space of at least 18 inches from the top layer of the duct to the street surface. The bottom of the trench should be level; and a bed of good cement concrete not less than 3 inches thick should be laid. The following instructions* for installing vitrified conduit may be considered as typical of the best up-to-date practice:

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*From the Catalogue of the Standard Underground Conduit Company.

Laying of. Conduit. When the trench has been properly prepared and the concrete foundation set, the laying of conduit should be begun. The ends of the conduit should be butted against the shoulder of the conduit terminal brick; short length should be used for the breaking of joints.

Care should be taken, when each length of conduit is laid, that the duct hole is perfectly clear and the conduit level. The work may then proceed; and if the following instructions are carried out, no difficulty will be encountered after the duct are laid.

When the first piece of conduit is laid and the keys inserted, one on the top and one on the side of the duct, the burlap for joints should be slipped partly under the conduit, and the next piece brought up and connected. The burlap is then brought up and wrapped around the conduit. After this operation is completed, a thin layer of cement mortar is plastered around the burlap, extending over the edges, so as to cover the scarified portion of the conduit so that it may adhere to it, thus making the joint practically water-tight.

The burlap should be first prepared in strips of not less than 6 inches in width, and of suitable length to wrap around the conduit, overlapping about 6 inches. If possible, the burlap should be saturated in asphaltum or pitch; but if this is not convenient, it may be dipped in water so as to stick to the conduit until the joint has been cemented. The engineer or foreman in charge should personally oversee the making of the joint, and especially see that the keys are inserted, as in many instances they are left out by the workmen, causing considerable trouble and expense. Sufficient time should be allowed for the joints to harden.

After the duct are laid, the sides are filled in with either concrete or dirt, as specified, care being taken that the conduit are not forced out of alignment by the careless filling-in of the sides. The top layer of concrete may then be laid and leveled.

After this the trench is ready for filling in.

In the laying of our self-centering single-duct conduit, no dowel-pins are used, the ducts being self-centering—one piece of conduit socketing into the other. Burlaping and cementing of joint is not necessary. Otherwise the instructions for the laying of multiple-duct should be followed. The use of a mandrel in laying self-centering conduit is superfluous.

As each section of the system—that is, from manhole to manhole—is completed, it should be rodded to insure the duct being clear. For this purpose wooden rods are employed, the rods being from 3 to 4 feet long by one inch in diameter and provided with brass couplings on the ends. The first rod is pushed into the duct chamber, the second one is then attached, and then the third and so on, until the first rod appears in the manhole at the opposite end.

A wooden mandrel about 10 inches long, made to conform to the shape of the duct, but about ¼ inch smaller in diameter, is attached to the last rod, and a galvanized-iron wire is then attached to the other end of the mandrel. The rods are drawn through the duct and uncoupled, until the mandrel has passed through the ducts. The wire is left remaining in the chamber, and secured in the manhole to prevent its being pulled out. The same operation is repeated until all the ducts are tested and wired. Should obstructions be met with and the mandrel bind, the location of the obstructions can readily be ascertained from the length of rod yet remaining in the duct, and can easily be removed. This method is far better than pulling the mandrel through as the ducts are laid, as in many cases the duct is obstructed or thrown out of alignment by the filling-in of the concrete or trench, and this would not be noticed until an attempt was made to draw the cable. The wire left in the duct is used in drawing the cables.

Fibre Conduit. This type of conduit consists of wood fibre formed into a tube over a mandrel under pressure. After the tube is formed on the mandrel, it is removed, and, after being dried in air, is placed in a tank of preservative and insulating compound.

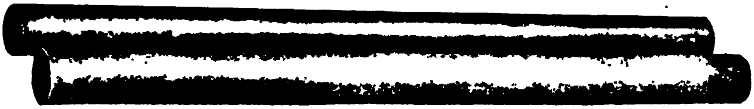


Fig. 74. Socket-Joint Fibre Conduit.

Fibre conduits are made in three different styles—namely, the *socket-joint*, *sleeve-joint*, and *screw-joint* types, shown respectively in Figs. 74, 75, and 76. The forms of conduit here shown are made by the Fibre Conduit Company, of Orangeburg, New York.

In the socket-joint type, the connections between the lengths of conduit are made by means of male and female joints turned on the ends of the conduit so that it is necessary only to push one length within the other to secure alignment without the use of a sleeve-coupling or other device. While this is the cheapest and simplest form of fibre conduit, the joint is not so secure as in either of the other two types.

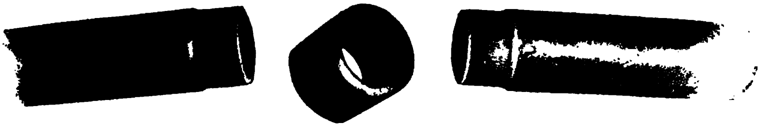


Fig. 75. Sleeve-Joint Fibre Conduit.

The sleeve-joint fibre conduit has the ends of each joint turned so that a sleeve may be slipped over the turned portion and butted up against the shoulder on the tubes. These sleeves are about 4 inches long and ⅜ inch thick. While this form of joint is more secure than the socket type, it is not so secure as the screw-joint type.

The screw-joint type of fibre conduit is manufactured with a slightly thicker wall than the socket-joint type, in order to obtain the necessary thickness for getting the thread on the end of the pipe. The sleeve in this case is threaded; and, instead of being slipped on the conduit, as in the case of the sleeve-joint type, it is screwed on, and the thread may be filled with compound and a water-tight joint thereby obtained. Various special forms of elbows, bends, junction-boxes, tees, etc., are provided for this conduit, for special connections. Couplings are also made so that joints can be made between fibre conduit and iron pipe, where it is desirable to make such a connection.

The advantages of fibre conduit are—*first*, that it is lighter than any of the other forms of conduit, which reduces the cost of transportation, carting, and handling; and *second*, that the cost of labor for installing it is less than in the case of iron pipe, and less than that of the single-duct tile pipe. Table XII gives the principal data relating to fibre conduit.

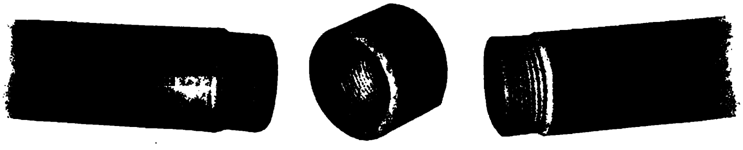


Fig. 76. Screw-Joint Fibre Conduit.

TABLE XII

Fibre Conduit

Inside Diameter (Inches)	Type of Conduit	Length (Feet)	Thickness of Wall (Inches)	Approx. Weight per Foot (lbs.)
1	Socket-joint	2-½	¼	0.50
1½	" "	5	¼	0.70
2	" "	5	¼	0.85
2½	" "	5	¼	1.02
3	" "	5	¼	1.20
3½	" "	5	¼	1.40
4	" "	5	¼	1.60
1½	Sleeve-joint	5	¼	0.80
2	" "	5	¼	0.95
2½	" "	5	¼	1.15
3	" "	5	7/16	2.40
3½	" "	5	7/16	2.90
4	" "	5	½	3.33
1½	Screw-joint	5	5/16	1.00
2	" "	5	⅜	1.45
2½	" "	5	⅜	1.75
3	" "	5	7/16	2.40
3½	" "	5	7/16	2.90
4	" "	5	½	3.33

Fig. 77 shows the method of laying fibre conduit in a trench.

A concrete bed should be provided for all three types of fibre conduit. Where the ground is moist or where there is likelihood of water getting in the joints, it is advisable to make a complete envelope around the conduit.

The joints should be carefully dipped in or coated with a special liquid compound provided for this purpose, so as to insure watertightness. The cables should be spaced about 1½ inches apart, by means of wooden separators; and the spaces between the ducts, and between the walls of the trench and the outer ducts, should be filled with a thin grouting of cement and sand. If more than one horizontal row of ducts are installed, the grouting of each row should be smoothed over so as to prepare a base for the next row of ducts.

To fish the conductors in fibre conduit, it is not necessary to follow the method of rodding usually required with vitrified conduits; but it is found that by utilizing a solid No. 6 iron wire, and fishing from one manhole to the next, the mandrels and brush can be attached to the end of the wire and pulled through the conduits, thus insuring that the joints are smooth and that there are no obstructions in the conduit. To prevent accidental clogging of the ends of the conduit, wooden plugs should be installed in the openings of all unfinished conduit work, or in all unoccupied cable ducts at manholes.

Drawing In the Cables. After the conduits have been tested by means of the mandrel to ascertain that they are continuous and that the joints are smooth, the work of installing the cables may be started. Special precaution should be taken to prevent sharp bending of the cables, and thus to prevent injury to the lead sheathing of the rubber insulation. If the cable is light and of small diameter, the distance not over 300 feet, and the run fairly straight, the cable can usually be pulled in by hand; but often other means must be provided so as to secure sufficient power. Precautions should be taken, however, to avoid placing too great a strain on the cables, as it is liable to injure them, and the injuries may not show up immediately, but may cause trouble later. The remedy is to avoid placing the manholes too far apart, and to have the runs as straight as possible; also to properly test the conduits for continuity and smoothness before starting to install the cables. Enough slack should be left in each manhole to allow the cables to pass close to the side walls of the manhole, and to have the centers free and accessible for a man to enter the manhole. Where there are a great number of cables in a manhole, shelves or other supports should be

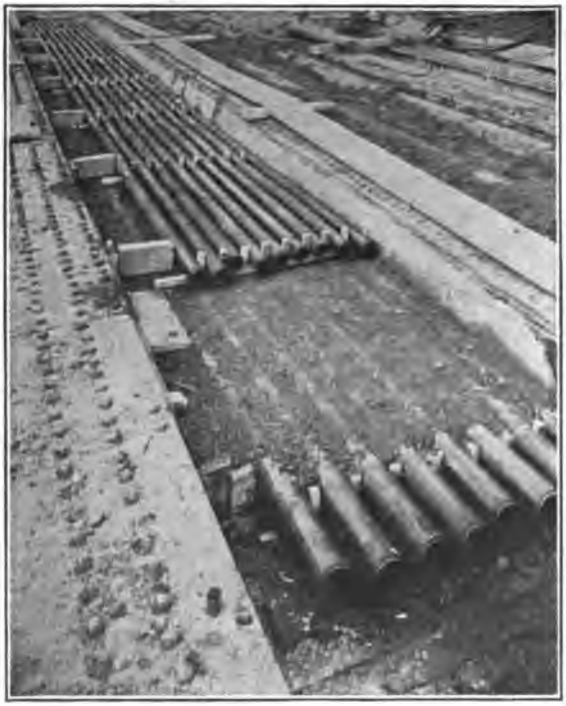


Fig. 77. Method of Laying Fibre Conduit in Trench.

provided for holding the cables apart and in position. Where two or more conductors are placed in the same duct, they should always be pulled in at the same time, for otherwise the cables last pulled in are apt to injure those already installed.

Manholes. Manholes should be provided about every 300 feet, in order to facilitate the installation of the conductors in the duct. The exact distance between manholes should be determined by conditions; in some cases they should be placed even closer together than the figure given, while in other cases their distance apart might be slightly greater.

Manholes are built of concrete or brick, and provided with a cast-iron frame or cover. The manholes may be of square, round, rectangular, or oval section, the last-mentioned form of manhole being probably the best, as it avoids the liability to sharp bends or kinks being made in the cable. The manhole cover may be of the same form as the manhole itself, or it may be of different form; but round or square covers are usually used. Fig. 78 shows a standard form of manhole used in New York City. This manhole is substantially built, and adapted for heavy traffic passing over the cover. For suburban or country work, manholes may be made of lighter construction.

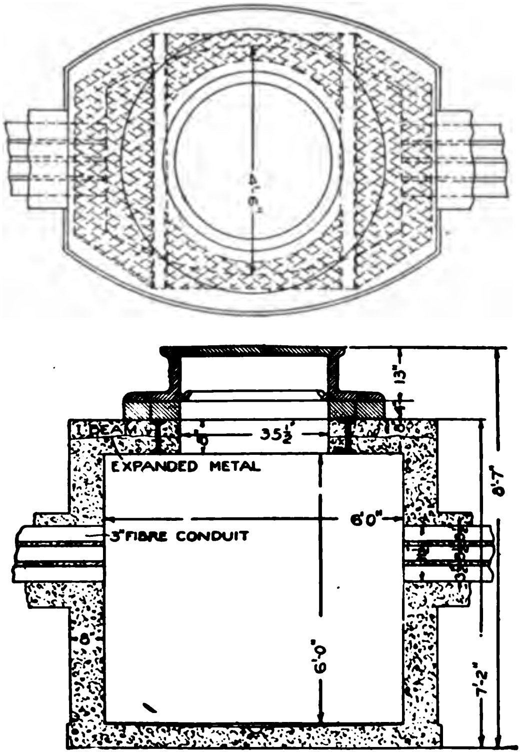
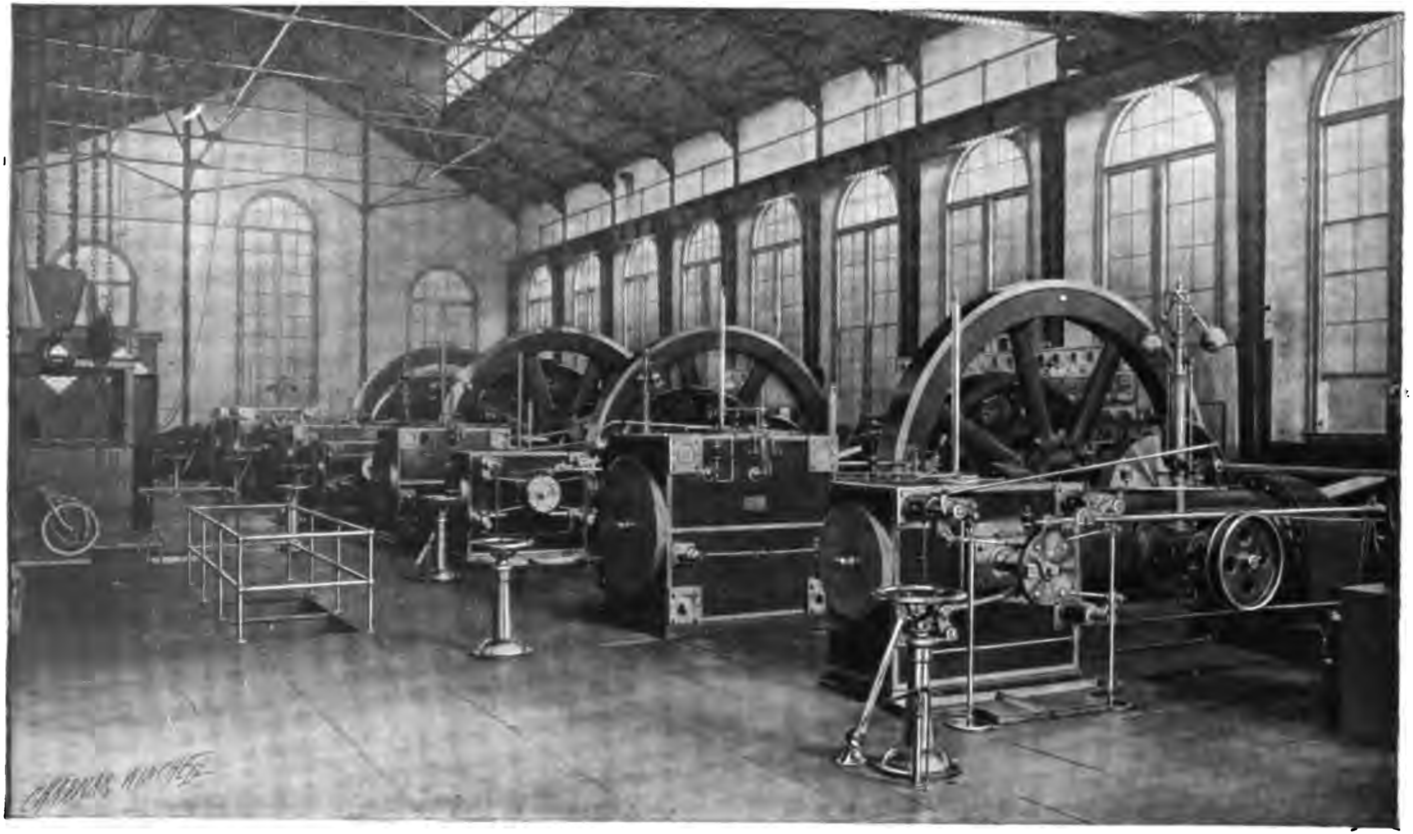


Fig. 78. Plan and Sectional Elevation of Standard Form of Manhole Used in New York City.



CROSS-COMPOUND CONDENSING CORLISS ENGINES.

Direct-Connected to Electric Railway Generators.

The C. and G. Cooper Company.

ELECTRIC BELL WIRING.

In wiring for electric bells to be operated by batteries, the danger of causing fires from short circuits or poor contacts does not exist as in the case of wiring for light and power, because the current strength is so small. Neither is the bell-fitter responsible to city inspectors or fire underwriters. On this account, bell fitting is too often done in a careless and slovenly manner, causing the apparatus to give unsatisfactory results and to require frequent repairs, so that the expense and inconvenience in the end far more than offset any time saved by doing an inferior grade of work. Hence, at the outset it is well to state that as much care should be taken in the matter of joints and insulation of bell wiring as in wiring for light or power.

If properly installed, the electric bell forms a reliable and yet inexpensive means of signaling, and is far superior to any other. On this account practically every new building is fitted throughout with electric bells.

In addition to the necessity of thoroughness already mentioned, care should be taken to use only reliable apparatus which must be installed in accordance with the fundamental principles on which its satisfactory operation depends.

WIRE.

The common sizes of wire in use for bell work are Nos. 18, 20, and 22. In general, however, No. 20 will be found satisfactory as it is usually sufficiently large, while in many cases No. 22 is not strong enough from a mechanical standpoint.

It is important that the wires should be well insulated to prevent accidental contacts with the staples or other wires. First of all the wire should be tinned, as this prevents the copper from being acted upon by the sulphur in the insulation. It also facilitates soldering. The inner coating of insulation should be of

Fig. 1.

india rubber, surrounded by several longitudinal strands of cotton, outside of which are wound several strands of colored cotton laid on spirally. This is next immersed in melted paraffin wax and polished by friction. A short length of approved electric bell wire is shown in Fig. 1.

When ordering wire, it is well to have it furnished in several different colors as this greatly facilitates both the original installation and later repairs, because in this way one line may be distinguished from another, taps from main lines, etc. Moreover, a faulty wire having been found, it is possible to identify it at any desired section of its length.

METHODS OF WIRING.

In running wires, the shortest and most direct route should, of course, be taken between the battery, bells, and bell pushes. There are two cases to be considered. The better method is that in which the wires are run before the building is completed, and the wiring should be done as soon as the roof is on and the walls are up. In this case the wires are usually run in zinc tubes secured to the walls with nails. The tubes should be from $\frac{3}{8}$ inch to $\frac{1}{2}$ inch in diameter, preferably the latter. It is better to place the wires and tubes simultaneously, but the tubes may be put in place first and the wires drawn in afterward, although this latter plan has the objection that the insulation is liable to become abraded when the wires are drawn in. In joining up two lengths of tube, the end of one piece should be opened up with the pliers so that it may receive the end of the other tube, which should also be opened up, but to a less extent, to prevent wear upon the insulation. Specially prepared paper tubes are sometimes substituted for the zinc.

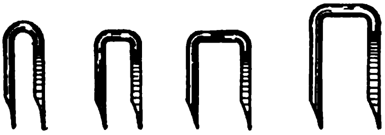


Fig. 2.

If the building is completed before the wiring is done, the concealed method described above cannot be used, and it is necessary to run the wires along the walls supported by staples, where they will be least conspicuous. Fig. 2 shows ordinary double-pointed tacks, Fig. 3 shows an insulating saddle staple which is to be recommended. Two wires should never be secured under the same staple if it can possibly be avoided, owing to the danger of short circuits. With a little care it is usually possible to conceal the wiring behind the picture moulding, along the skirting-board, and beside the door posts, but where it is impossible to conceal it, a light ornamental casing to match the finish of the room, may be used. It is sometimes advisable to use twin wires or two insulated wires run in the same outer covering.

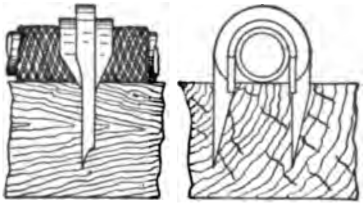


Fig. 3.

In some cases it is well to run the wires under the floors, laying them in notches in the tops of the joists or in holes bored about two inches below the tops of the joists.

JOINTS.

When making a joint, care should be taken to have a firm, clean connection, both mechanically and electrically, and this must always be soldered to prevent corrosion. The insulation should be stripped off the ends of the wires to be joined, for a distance of about 2 inches, and the wires made bright by scraping or sandpapering. They should then be twisted tightly and evenly together as shown in Fig. 4.

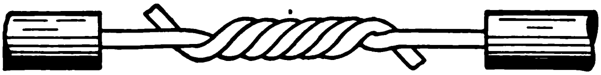


Fig. 4.

Next comes the operation of **soldering,** which is absolutely necessary if a permanent joint from an electrical standpoint is to be obtained. A joint made without solder may be electrically sound at first, but its resistance rapidly increases, due to deterioration of the joint. As has already been stated, the wires should be made bright and clean before they are twisted together. Soldering fluids should never be used, because they cause corrosion of the wire. The best flux to use is resin or composite candle. The soldering should always be done with a copper bit rather than with a blowpipe or wireman's torch.

A convenient form of soldering tool consists of a small copper bit having a semicircular notch near the end. This bit should, of course, be well tinned. It is then heated over a spirit lamp, or wireman's torch, and the notch filled with soft solder. Lay the joint, which has previously been treated with the flux, in this notch and turn it so that the solder runs completely around among the spirals of the joint. The loose solder should be shaken off or removed with a bit of rag. When the joint is set, it should be insulated with rubber tape, so that it will be protected as perfectly as the other portions.

It is often possible to save a considerable length of wire and amount of labor by using a ground return, which, if properly arranged, will give very satisfactory results, although a complete metallic circuit is always to be preferred. Where water or gas mains are available, a good ground may be obtained by connecting to them, being sure to have a good connection. This may be secured by scraping a portion of the pipe perfectly bright and clean and then winding this with bare wire; the whole is then well soldered. An end should be left to which the wire from the bell circuit is twisted and soldered. If such mains are not available, a good ground can be obtained by connecting the wire from the bell circuit, as described above, to a pump pipe. In the absence of water and gas mains, and of a pump pipe, a ground may be obtained by burying beneath permanent moisture level a sheet of copper or lead, having at least five square feet of surface, to which the return wire is connected. The ground plate should be covered with coke nearly to the surface; the hole should then be filled in with ordinary soil well rammed.

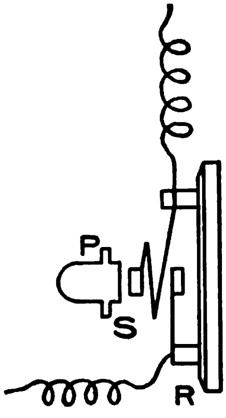


Fig. 5.

OUTFIT.

The three essential parts of the electric bell outfit are the bell push, which furnishes a means of opening and closing the circuit at will, the battery, which furnishes the current for operating the bell, and the bell itself. Before discussing the combination of these pieces of apparatus in the complete circuit, let us take up the individual parts in order.

A bell push is shown diagrammatically in Fig. 5. In this illustration P is the push button; when this is pressed upon it brings the point of the spring S in contact with the metal strip R, thus closing the circuit with which it is connected in series. Normally the springs are separated as shown, and the circuit is accordingly open.

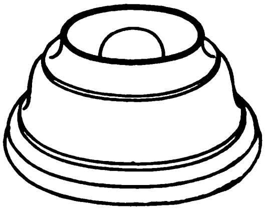


Fig. 6.

Bell pushes are made in various designs and styles, from the simple wooden push shown in Fig. 6 to very elaborate and expensive articles. Fig. 7 shows four cast bronze pushes of neat appearance and moderate price.

Batteries. Electric bells are nearly always operated on the open circuit plan, and hence the battery used is generally of the open circuit type, such as the Leclanche cell, which is used very largely except for heavy work. This is a zinc-carbon cell in which the excitant is sal-ammoniac dissolved in water. Polarization is prevented by peroxide of manganese, which gives up part of its oxygen, combining with the hydrogen set free and forming water.

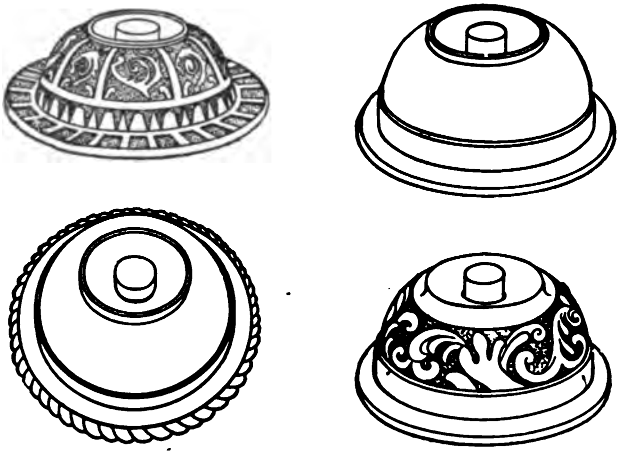


Fig. 7.

Dry Batteries are also frequently used for bell work, their principal advantage being cleanliness, as they cannot spill. Dry cells are really a modification of the Leclanche type, as they use zinc and carbon plates and sal-ammoniac as the exciting agent. The Burnley cell, which is one of the principal types of dry cell, has an electrolyte composed of sal-ammoniac, chloride of zinc, plaster, flour, and water. This compound when mixed is a semi-liquid mass which quickly stiffens after being poured into the cup. The depolarizing agent is peroxide of manganese, the same as is used in the Leclanche cell, this being packed around the carbon cylinder. The top of the cell is sealed with bitumen or some similar substance.

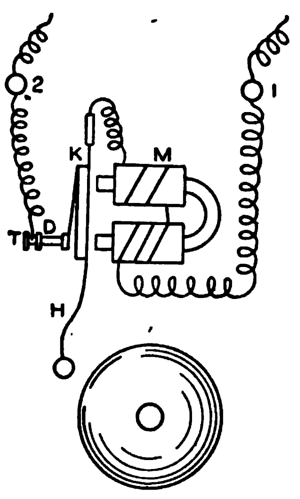


Fig. 8.

For very heavy work the Edison-Lalande and the Fuller types of cell are best suited, while for closed circuit work the gravity cell is most satisfactory.

Bell. It is a well-known fact that if a current of electricity flows through a coil of wire wound on an iron core, the core becomes magnetized and is capable of attracting any magnetic substances to itself. The operation of the electric bell, like that of so many other pieces of electrical apparatus, depends upon this fact. A diagrammatic representation of an electric bell is shown in Fig. 8, in which M is an electromagnet composed of soft-iron cores on which are wound coils of insulated wire. The armature is mounted upon a spring K, and carries a hammer H at its end for striking the gong. On the back of the armature is a spring which makes contact at D with the back stop T. The action of the bell is as follows: When the circuit is closed through the bell a current flows from terminal 1, around the coils of the magnet, through the spring K and contact point D, through the back stop T, to terminal 2. In flowing around the electromagnet the current magnetizes its core, which consequently attracts the armature. This causes the hammer H to strike the gong. While in this position the contact at D is broken, the current ceases to flow around the electromagnet and the cores consequently lose their attractive force. The armature is then carried back to its original position by the spring K, making contact at D, and the process is repeated. The hammer will thus vibrate and the bell continue to ring as long as the circuit is closed.

The type of bell described above is the one most commonly used. Such bells are made in a great variety of shapes and styles, the prices varying accordingly. It is important that platinum tips be furnished at the contact point D, Fig. 8, to prevent corrosion. The bells on the market today are of two classes, the iron box bell and the wooden box bell. A bell of the wooden box type is shown in Fig. 9, and a higher grade bell of the iron frame skeleton type is shown in Fig. 10. Bells without covers should never be used, as dust will settle on the contacts and interfere with their action.

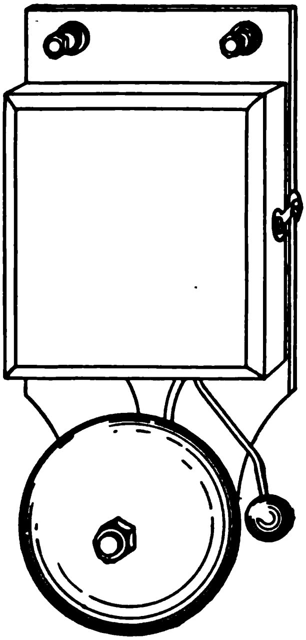


Fig. 9.

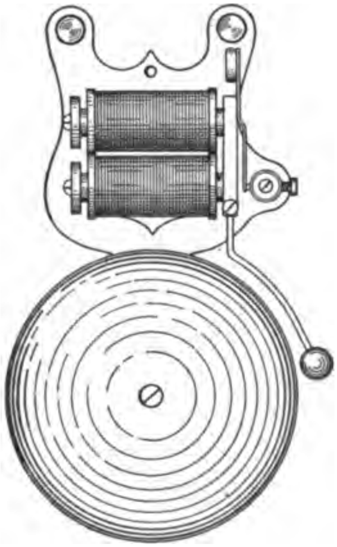


Fig. 10.

CIRCUITS.

The possible combinations of the various parts into complete circuits are so varied that it would be impossible to describe them all; in fact, almost every one is to a certain extent a special problem. It is, however, possible to give typical circuits the underlying principles of which can be applied successfully to any particular case.

Fig. 11 shows a bell circuit in its simplest form, in which P represents the push, B the bell, and C the battery; all connected in series. The circuit is normally open at P, and hence no current flows to exhaust the batteries. When P is pressed, the circuit, otherwise complete, is closed and current passes through the bell causing it to ring, as already explained. For instance, the push might be located beside the front door, the bell in the kitchen and the battery in the cellar; the location depending on the results desired and conditions to be met. The wire between P and C may, if necessary, be dispensed with and connection made to ground at G and G, as shown by the dotted lines.

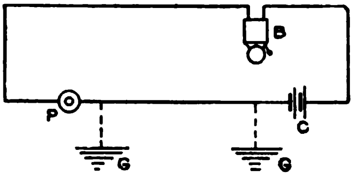


Fig. 11.

Fig. 12 shows an arrangement by means of which one bell B may be controlled by either of the pushes P or P′. This system may be extended to any number of pushes similarly connected.

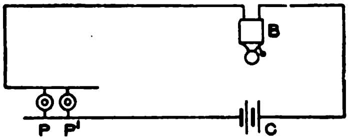


Fig. 12.

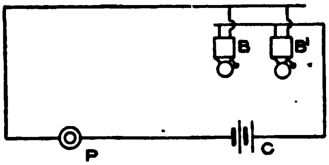


Fig. 13.

A method for ringing two bells simultaneously from one push is shown in Fig. 13, where both bells B and B′ will ring from push P. Bells, if connected in this manner, should have as nearly as possible the same resistance, otherwise the bell of lower resistance will take so much current that there will not be a sufficient amount left for the other. Also, the batteries must be of greater current capacity as the amount of current taken is, of course, doubled. This system can be extended to any number of bells connected in this way, up to the limit of capacity of the battery to ring them. Figs.

12 and 13 may be combined so that two or more bells may be rung from any one of two or more pushes.

In Fig. 14 is shown a scheme for ringing either bell, B or B′, from one push and one battery by means of the two-point switch S. When the arm of the switch is on contact 1, the push will ring bell B, and when on contact 2 it will ring bell B′.

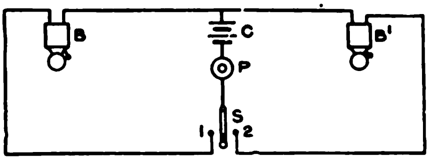


Fig. 14.

In Fig. 15 is shown a method of connecting bells in series so that B and B′ may be rung from P. If all the bells so connected were of the vibrating type, they would not work satisfactorily, as it would be impossible to time them so that the vibrations would keep step, hence only one bell should be of the vibrating type, and the others should have the circuit breakers short-circuited, the vibrating bell serving as interrupter for the whole series. Obviously this system requires a higher voltage than parallel connection, and the cells must be of sufficient E.M.F. to ring the bells satisfactorily. Several bells may be connected in this way, if desired, up to the limit of voltage of the battery.

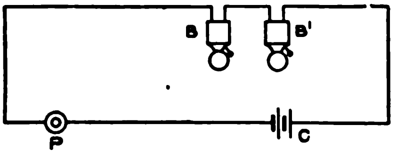


Fig. 15.

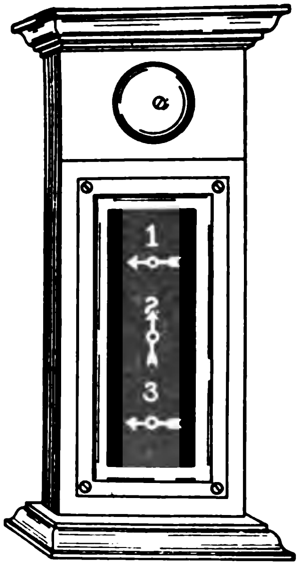


Fig. 16.

Oftentimes a bell is to be rung from several different places. For instance, the bell in an elevator may be rung from any one of several floors, or the bell in the office of a hotel may be rung from any one of several different rooms. In this case it is necessary to have some device to indicate from which push the bell was rung. The annunciator furnishes this information very well. A three-station annunciator is shown in Fig. 16. The connections for an annunciator are shown in Fig. 17 where A represents the annunciator, B the bell, C the battery, and P^1, P^2, and P^3 the pushes. For instance, when P^1 is pressed, the current passes through the electromagnet controlling point 1 on the annunciator which causes the arrow to be turned and at the same time the bell rings. After the attendant has noted the signal, the arrow is restored to its normal position by pressing a lever on the bottom of the annunciator box.

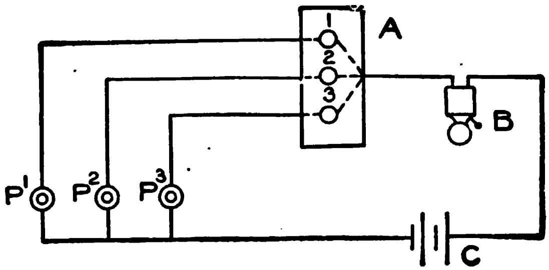
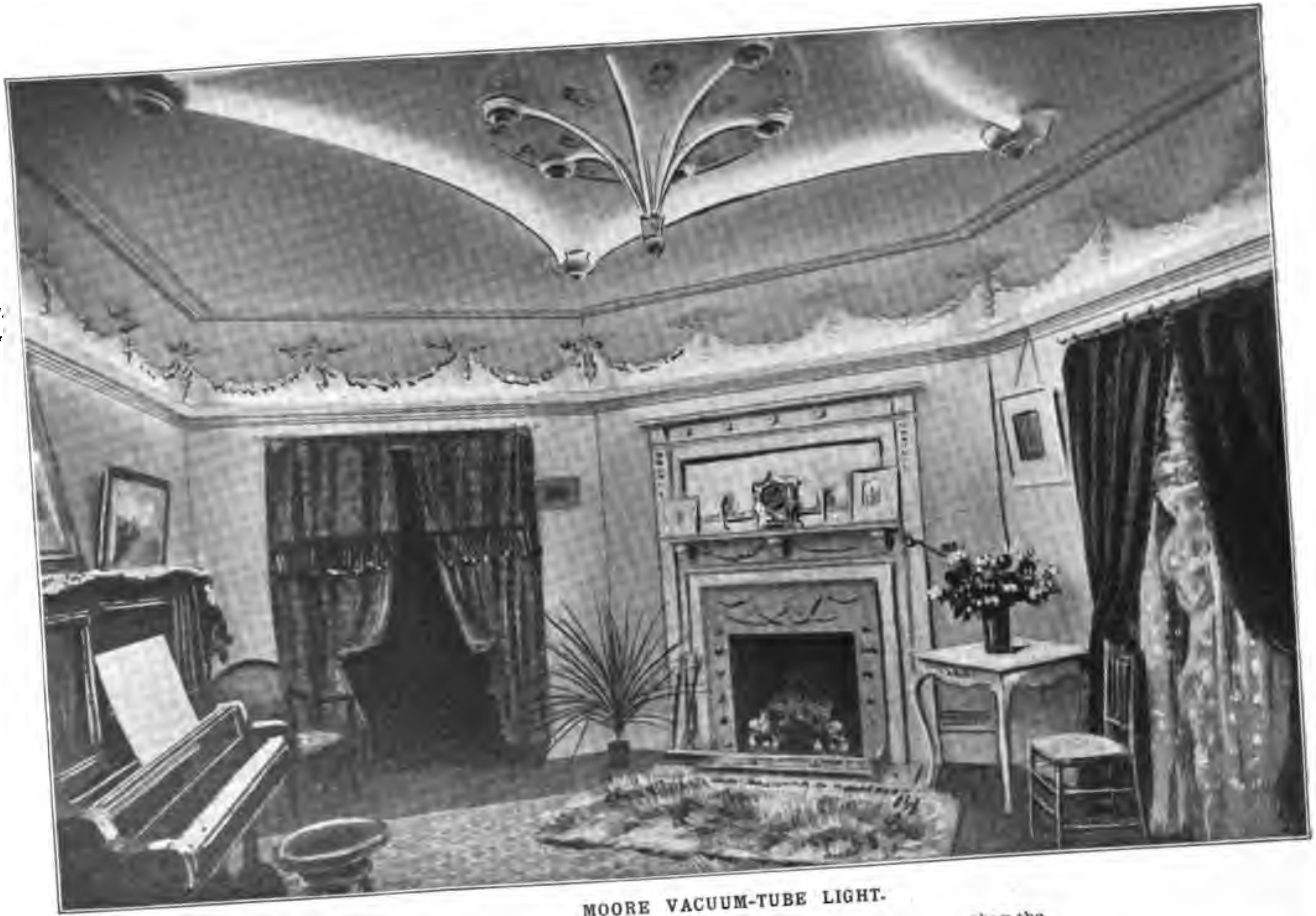


Fig. 17.

The electric burglar alarm furnishes a very efficient protection and is an application of the principles already described. The circuit, instead of being completed by a push, is completed by contacts placed on the doors or windows so that the opening of either will cause the bell to ring. The same device may be used on money-drawers, safes, etc.

In the case of the electric fire alarm, the signal may be given either automatically when the temperature reaches a certain degree, or pushes may be placed in convenient locations to be operated manually. The pushes should be protected by glass so that they will not be tampered with, it being necessary to break the glass to give the alarm.



MOORE VACUUM-TUBE LIGHT.

Designed to Actually Imitate Daylight with a Better Efficiency than the Incandescent Lamp

ELECTRIC LIGHTING.

HISTORY AND DEVELOPMENT.

The history of electric lighting as a commercial proposition begins with the invention of the Gramme dynamo (by Z. J. Gramme) in 1870, together with the introduction of the Jablochkoff candle or light, which was first announced to the public in 1876, and which formed a feature of the International Exposition at Paris in 1878. Up to this time, the electric light was known to but few investigators, one of the earliest being Sir Humphrey Davy who, in 1810, produced the first arc of any great magnitude. It was then called the "voltaic arc", and resulted from the use of two wood charcoal pencils as electrodes and a powerful battery of voltaic cells as a source of current.

From 1840 to 1859, many patents were taken out on arc lamps, most of them operated by clockwork, but these were not successful, due chiefly to the lack of a suitable source of current, since all depended on primary cells for their power. The interest in this form of light died down about 1859, and nothing further was attempted until the advent of the Gramme-dynamo.

The incandescent lamp was but a piece of laboratory apparatus up to 1878, at which time Edison produced a lamp using a platinum spiral in a vacuum, as a source of light, the platinum being rendered incandescent by the passage of an electric current through it. The first successful carbon filament was made in 1879, this filament being formed from strips of bamboo. The names of Edison and Swan are intimately connected with these early experiments.

From this time on, the development of electric lighting has been very rapid, and the consumption of incandescent lamps alone has reached several millions each year. When we compare the small amount of lighting done by means of electricity twenty-five years ago with the enormous extent of lighting systems and the numerous applications of electric illumination as they are today, the growth and development of the art is seen to be very great, and the value of a study of this subject may be readily appreciated. While in many cases electricity is not the cheapest source of power for illumination, its admirable qualities and convenience of operation make it by far the most desirable.

Classification. The subject of Electric Lighting may be classified as follows:

1. The type of lamps used.
2. The methods of distributing power to the lamps.
3. The use made of the light, or its application.
4. Photometry and lamp testing.

Taking up these branches in the order named, we may further subdivide the types of lamps used into:

1. Incandescent lamps.
2. Arc lamps.
3. Special lamps, or lamps which do not require carbon, such as the Nernst lamp, Cooper-Hewitt lamp, etc.

The Incandescent Lamp. The incandescent lamp is by far the most common type of lamp used, and the principle of its operation is as follows:

If a current I is sent through a conductor whose resistance is R, for a time t, the conductor is heated, and the amount of heat generated is:

Heat generated $= I^2R\,t$, $I^2R\,t$ representing joules or watt-seconds.

If the current, material, and conditions are so chosen that the substance may be heated in this way until it gives out light, becomes incandescent, and does not deteriorate too rapidly, we have an incandescent lamp. Carbon is the substance chosen for this conductor and for ordinary lamps it is formed into a small thread or filament. Carbon is selected for two reasons:

1. The material must be capable of standing a very high temperature, 1280 to 1330° C.

2. It must be a conductor of electricity with a fairly high resistance.

Platinum has been used for the material, but, as we shall see, its temperature cannot be maintained at a value high enough to make the lamp as efficient as when carbon is used. Nearly all attempts to substitute another substance in place of carbon have failed, and the few lamps which are partially successful will be treated under the head of special lamps. The nature of the carbon employed in incandescent lamps has, however, been much improved over the first forms, and the method of manufacture will be treated next.

MANUFACTURE OF INCANDESCENT LAMPS.

Preparation of the Filament. Cellulose, a chemical compound rich in carbon, is prepared by treating absorbent cotton with zinc chloride in proper proportions to form a uniform, gelatine-like mass. It is customary to stir this under a partial vacuum in order to remove bubbles of air which might be contained in it and destroy its uniformity. This material is then forced, "squirted," through steel dies into alcohol, the alcohol serving to harden the soft, transparent threads. These threads are then thoroughly washed to remove all trace of the zinc chloride, dried, cut to the desired lengths, wound on forms, and carbonized by heating to a high temperature away from air. During carbonization, the cellulose is transformed into pure carbon, the volatile matter being driven off by the high temperature to which the filaments are subjected. The material becomes hard and stiff, assuming a permanent form, shrinking in both length and diameter; the form being specially constructed so as to allow for this shrinkage. The forms are made of carbon blocks which are placed in plumbago crucibles and packed with powdered carbon; the crucibles are covered with loosely fitting carbon covers. The crucibles are gradually brought to a white heat, at which temperature the cellulose is changed to carbon, and then allowed to cool. After cooling, the filaments are removed, measured and inspected, and the few defective ones discarded.

In the early days, these filaments were made of cardboard or bamboo, and later of thread treated with sulphuric acid.

A few of the shapes of filaments now in use are shown in Fig. 1, the different shapes giving a slightly different distribution of light. The shapes here shown are designated as follows: A, U-shaped; B, single-curl; C, single-curl anchored; D, double-loop; E, double-curl; F, double-curl anchored.

Mounting the Filament. After carbonization, the filaments are mounted or joined to wires leading into the globe or bulb. These wires are made of platinum—platinum being the only substance, so far as known, that expands and contracts the same as glass with change in temperature and which, at the same time, will not be melted by the heat developed in the carbon. Since the bulb must remain air-tight, a substance expanding at a different rate from the glass cannot be used. Several methods of fastening the filament to the "leading in" wires have been used, such as forming a socket in the end of the wire, inserting the filament and then squeezing the socket tightly against the carbon, and the use of tiny bolts when cardboard filaments were used, but the pasted joint is now used almost exclusively. Finely powdered carbon is mixed with some adhesive compound, such as molasses, and this mixture is used as a paste for fastening the carbon to the platinum. Later, when current is sent through the joint, the volatile matter is driven off and only the carbon remains. This makes a cheap and, at the same time, a very efficient joint.

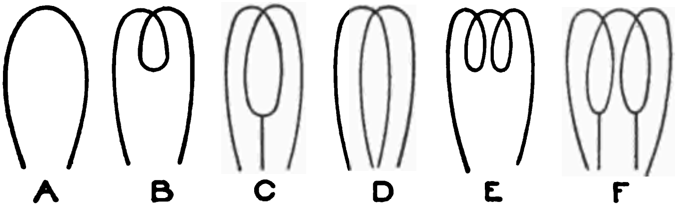


Fig. 1.

Flashing. Filaments, prepared and mounted in the manner just described, are fairly uniform in resistance, but it has been found that their quality may be much improved and their resistance very closely regulated by depositing a layer of carbon on the outside of the filament by the process of "flashing". By flashing is meant heating the filament to a high temperature when immersed in a hydrocarbon gas, such as gasoline vapor, under partial vacuum. Current is passed through the filament in this process to accomplish the heating. Gas is used, rather than a liquid, to prevent too heavy a deposit of the carbon. Coal gas is not recommended because the carbon, when deposited from this, has a dull black appearance. The effects of flashing are as follows:

1. The diameter of the filament is increased by the deposited carbon and hence its resistance is decreased. The process must be discontinued when the desired resistance is reached. Any little irregularities in the filament will be eliminated since the smaller sections, having the greater resistance, will become hotter than the remainder of the filament and the carbon is deposited more rapidly at these points.

2. The character of the surface is changed from a dull black and comparatively soft nature to a bright gray coating which is much harder and which increases the life and efficiency of the filament.

Exhausting. After flashing, the filament is sealed in the bulb and the air exhausted through the tube A in Fig. 2, which shows the lamp in different stages of its manufacture. The exhaustion is accomplished by means of mechanical air pumps, supplemented by Sprengle or mercury pumps and chemicals. Since the degree of exhaustion must be high, the bulb should be heated during the process so as to drive off any gas which may cling to the glass. When chemicals are used, as is now almost universally the case, the chemical is placed in the tube A and, when heated, serves to take up much of the remaining gas. Exhaustion is necessary for several reasons :

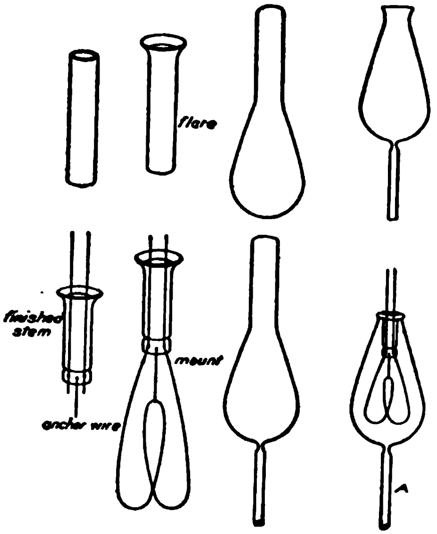


Fig. 2.

1. To avoid oxidization of the filament.
2. To reduce the heat conveyed to the globe.
3. To prevent wear on the filament due to currents or eddies in the gas.

After exhausting, the tube A is sealed off and the lamp completed for testing by attaching the base by means of plaster of Paris. Fig. 3 shows some of the forms of completed incandescent lamps.

Voltage and Candle-Power. Incandescent lamps vary in size from the miniature battery and candelabra lamps to those of several hundred candle-power, though the latter are very seldom used. The more common values for the candle power are 8, 16, 25, 32, and 50, the choice of candle-power depending on the use to be made of the lamp.

The voltage will vary depending on the method of distribution of the power. For what is known as parallel distribution, 110 or 220 volts are generally used. For the higher values of the voltage, long and slender filaments must be used, if the candle-power is to be low, and lamps of less than 16 candle-power for 220-volt circuits are not practical, owing to difficulty in manufacture. For series distribution, a low voltage and higher current is used, hence the filaments may be quite heavy. Battery lamps operate on from 4 to 24 volts, but the vast majority of lamps for general illumination are operated at or about 110 volts.

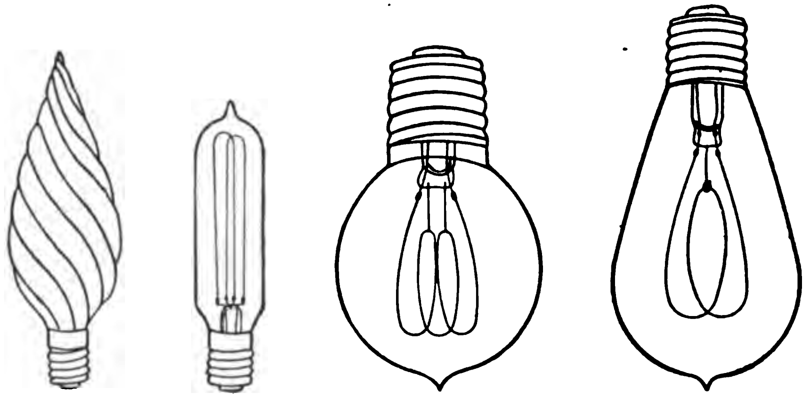


Fig. 3.

Efficiency. By the efficiency of an incandescent lamp is meant the power required at the lamp terminals per candle-power of light given. Thus, if a lamp giving an average horizontal candle-power of 16 consumes $\frac{1}{2}$ an ampere at 112 volts, the total number of watts consumed will be $112 \times \frac{1}{2} = 56$, and the watts per candle-power will be $56 \div 16 = 3.5$. The efficiency of such a lamp is said to be 3.5 watts per candle-power. "Watts economy" is sometimes used for "efficiency".

The efficiency of a lamp depends on the temperature at which the filament is run. This temperature is between 1280° and 1330° C, and the curve in Fig. 4 shows the increase of efficiency with the increase of temperature. The temperature attained by a filament depends on the rate at which heat is radiated and the amount of power supplied. The rate of radiation of heat is proportional to the area of the filament, the elevation in temperature, and the emissivity of the surface.

By emissivity is meant the number of heat units emitted from unit surface per degree rise in temperature above that of surrounding bodies. The bright surface of a flashed filament has a lower emissivity than the dull surface of an unheated filament, hence less energy is lost in heat radiation and the efficiency of the filament is increased.

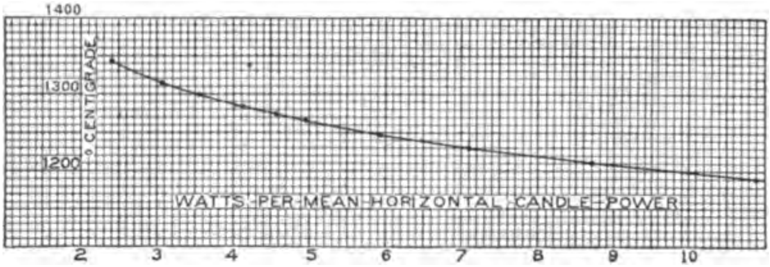


Fig. 4.

As soon as incandescence is reached, the illumination increases much more rapidly than the emission of heat, hence the increase in efficiency shown in Fig. 4. Were it not for the rapid disintegration of the carbon at high temperature, an efficiency higher than 3.1 watts could be obtained.

Relation of Life to Efficiency. By the useful life of a lamp is meant the length of time a lamp will burn before its candle-power has decreased to such a value that it would be more economical to replace the lamp with a new one than to continue to use it at its decreased value. A decrease to 80% of the initial candle-power is now taken as the point at which a lamp should be replaced, and the normal life of a lamp is in the neighborhood of 800 hours. To obtain the most economical results, lamps should always be replaced at the end of their useful life.

In Table 1 are given values of the efficiency and life of a 3.5-watt, 110-volt lamp for various voltages impressed on the lamp. These values are plotted in Fig. 5. These curves show that a 3% increase of voltage on the lamp reduces the life by one-half, while an increase of 6% causes the useful life to fall to one-third its normal value. The effect is even greater when 3.1-watt lamps are used, but not so great with 4-watt lamps. From this we see that the regulation of the voltage used on the system must be very good if high efficiency lamps are to be used, and this regulation will determine the type of lamp to be installed.

Selection of Lamps. Lamps taking 3.1 watts per candle-power will give satisfaction only when the regulation of voltage is the best—practically a constant voltage maintained at the normal voltage of the lamp.

TABLE I.

Effects of Change in Voltage.

Standard 3.5 Watt Lamp.

Voltage Per Cent. of Normal.	Candle-Power Per Cent. of Normal.	Watts Per Candle-Power.	Life Per Cent. of Normal.	Deterioration Per Cent. of Normal.
90	53	5.36		
91	56	5.09		
92	61	4.85		
93	65	4.63		
94	69	4.44	394	25
95	73	4.26	310	32
96	78	4.09	247	44
97	83	3.93	195	51
98	88	3.78	153	65
99	94	3.64	126	79
100	100	3.5	100	100
101	106	3.38	84	118
102	111	3.27	68	146
103	116	3.16	58	173
104	123	3.05	47	211
105	129	2.95	39	253
106	137	2.85	31	316
107	143	2.76	26	380
108	152	2.68	21	474
109	159	2.60	17	575
110	167	2.53	16	637

Lamps of 3.5 watts per candle-power should be used when the regulation is fair, say with a maximum variation of 2% from the normal voltage.

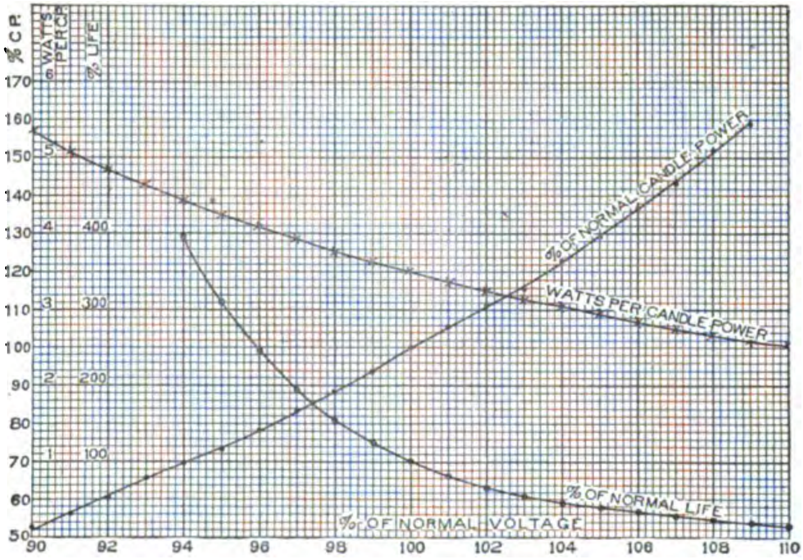


Fig. 5.

Lamps of 4 watts per candle-power should be installed when the regulation is poor. .These values are for 110-volt lamps. A 220-volt lamp should have a lower efficiency to give a long life.

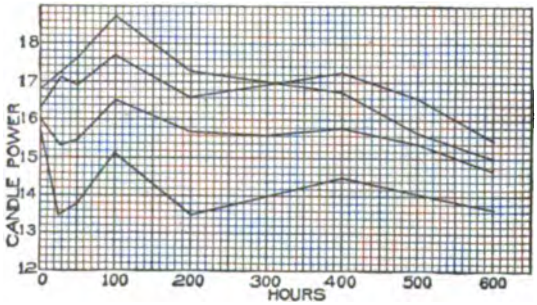


Fig. 6.

Lamps should always be renewed at the end of their useful life, this point being termed the "smashing-point", as it is cheaper to replace the lamp than to run it at the reduced candle-power. Some recommend running these lamps at a higher voltage, but that means at a reduced efficiency, and it is not good practice to do this.

Fig. 6 shows the life curves of a series of incandescent lamps. These curves show that there is an increase in the candle-power of some of the lamps during the first 100 hours, followed by a period during which the value is fairly constant, after which

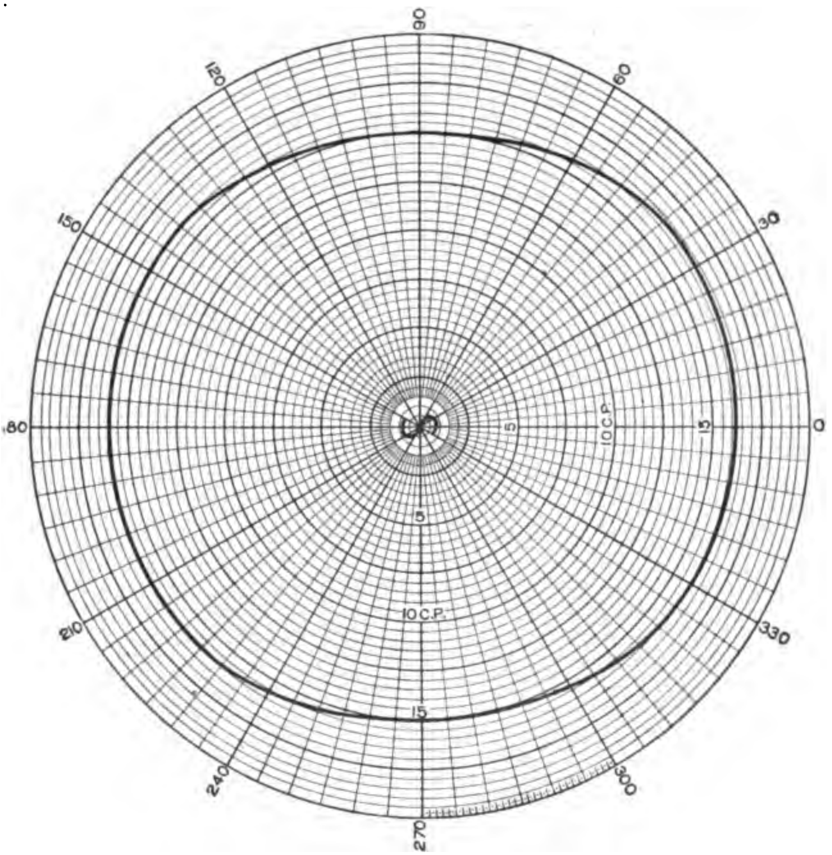


Fig. 7.

the light given by the lamp is gradually reduced to about 80% of the initial candle-power.

DISTRIBUTION OF LIGHT.

In Fig. 1 are shown various forms of filaments used in incandescent lamps, and Figs. 7 and 8 show the distribution of light from a single-loop filament of cylindrical cross-section.

Fig. 7 shows the distribution of light in a horizontal plane, the lamp being mounted in a vertical position, and Fig. 8 shows the distribution in a vertical plane. By changing the shape of the filament, the light distribution is varied. A mean of the readings taken in the horizontal plane forms the *mean horizontal candle-power*, and this candle-power rating is the one generally assumed for the ordinary incandescent lamp. A mean of the readings taken in a vertical plane gives us the mean vertical candle-power. but this value is of little use.

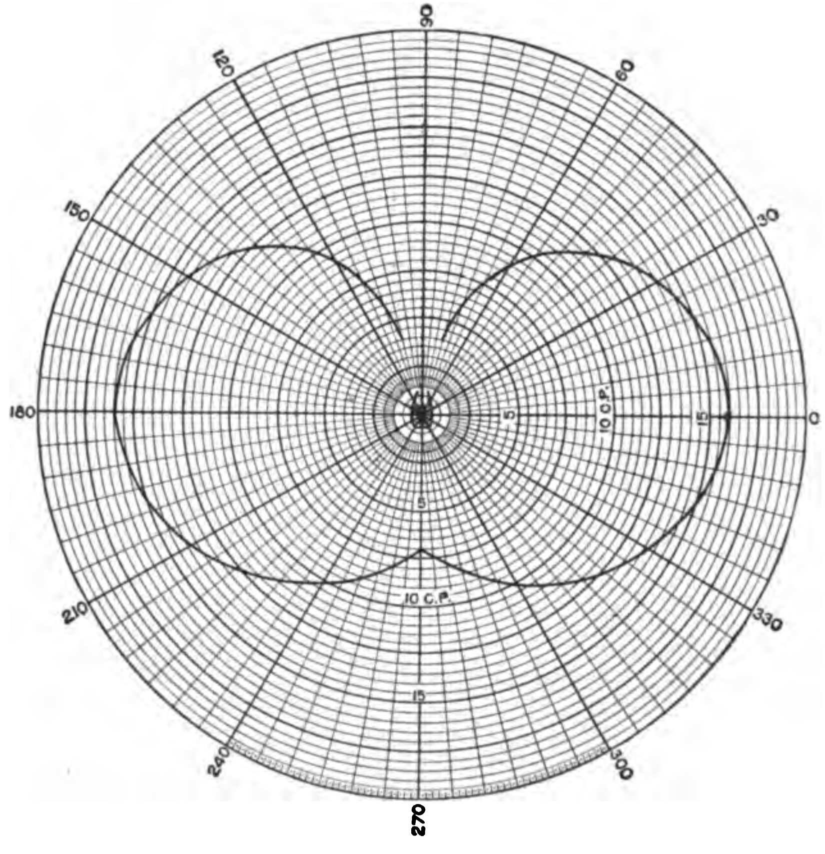


Fig. 8.

Mean Spherical Candle-Power. When comparing lamps which give an entirely different light distribution, the mean horizontal candle-power does not form a proper basis for such comparison, and the mean spherical or the mean hemispherical candle-power is used instead. By mean spherical candle-power is meant a mean value of the light taken in all directions. The methods for determining this will be taken up under *photometry*. The mean hemispherical candle-power has reference, usually, to the light given out below the horizontal plane.

ARC LAMPS.

The Electric Arc. Suppose two carbon rods are connected in an electric circuit, and the circuit closed by touching the tips of these rods together; on separating the carbons again the circuit will not be broken, provided the space between the carbons be not too great, but will be maintained through the arc formed at these points. This phenomenon, which is the basis of the arc light, was first observed on a large scale by Sir Humphrey Davy, who used a battery of 2,000 cells and produced an arc between charcoal points four inches apart.

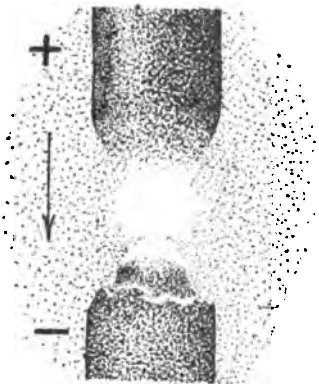


Fig. 9.

As the incandescence of the carbons across which an arc is maintained, together with the arc itself, forms the source of light for all arc lamps, it will be well to study the nature of the arc. Fig. 9 shows the general appearance of an arc between two carbon electrodes when maintained by direct current.

Here the current is assumed as passing from the top carbon to the bottom one as indicated by the arrow and signs. We find, in the direct-current arc, that the most of the light issues from the tip of the positive carbon, or electrode, and this portion is known as the *crater* of the arc. This crater has a temperature of from 3,000 to 3,500° C, the temperature at which the carbon vaporizes, and gives fully 80 to 85% of the light furnished by the arc. The negative carbon becomes pointed at the same time that the positive one is hollowed out to form the crater, and it is also incandescent but not to as great a degree as the positive carbon.

Between the electrodes there is a band of violet light, the arc proper, and this is surrounded by a luminous zone of a golden yellow color. The arc proper does not furnish more than 5% of the light emitted.

The carbons are worn away or consumed by the passage of the current, the positive carbon being consumed about twice as rapidly as the negative.

The light distribution curve of a *direct-current arc*, taken in a vertical plane, is shown in Fig. 10. Here it is seen that the maximum amount of light is given off at an angle of about 50° from the vertical, the negative carbon shutting off the rays of light that are thrown directly downward from the crater.

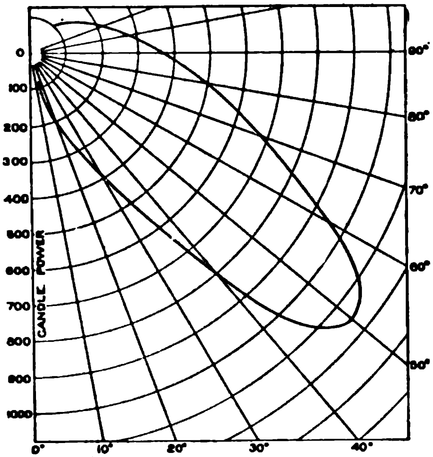


Fig. 10.

If alternating current is used, the upper carbon becomes positive and negative alternately, and there is no chance for a crater to be formed, both carbons giving off the same amount of light and being consumed at about the same rate. The light distribution curve of an *alternating-current arc* is shown in Fig. 11.

Arc Lamp Mechanisms. In a practical lamp we must have not only a pair of carbons for producing the arc, but also means for supporting these carbons, together with suitable arrangements for leading the current to them and for maintaining them at the proper distance apart. The carbons are kept separated the proper distance by the operating mechanisms which must perform the following functions:

1. The carbons must be in contact, or be brought into contact, to start the arc when the current first flows.
2. They must be separated at the right distance to form a proper arc immediately afterward.
3. The carbons must be fed to the arc as they are consumed.
4. The circuit should be open or closed when the carbons are entirely consumed, depending on the method of power distribution.

The feeding of the carbons may be done by hand, as is the case in some stereopticons using an arc, but for ordinary illumination the striking and maintaining of the arc must be automatic. It is made so in all cases by means of solenoids acting against the force of gravity or against springs. There are an endless number of such mechanisms, but a few only will be described here. They may be roughly divided into three classes:

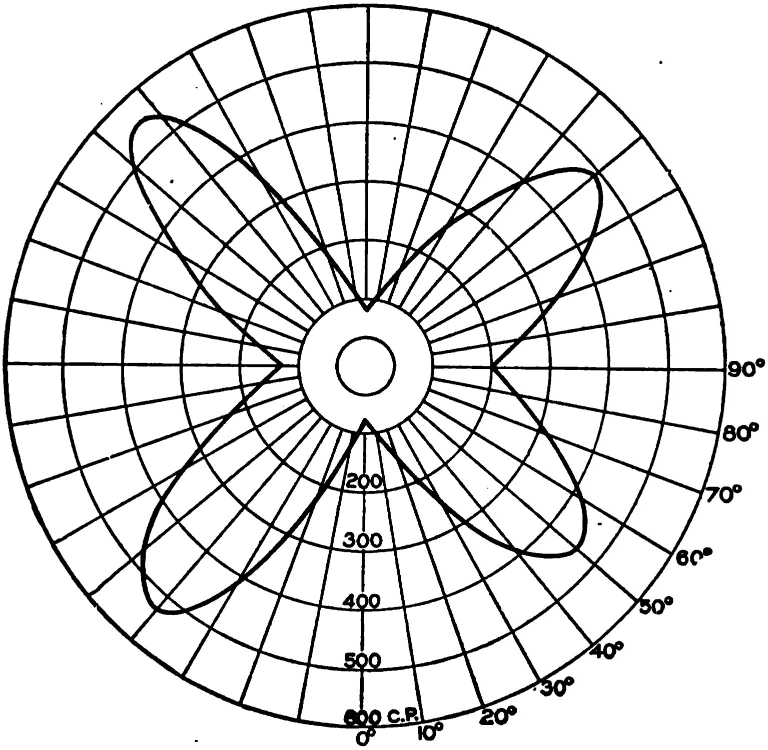


Fig. 11.

1. Shunt Mechanisms.
2. Series Mechanisms.
3. Differential Mechanisms.

In **Shunt Lamps**, the carbons are held apart before the current is turned on, and the circuit is closed through a solenoid connected in across the gap so formed. All of the current must pass through this coil at first, and the plunger of the solenoid is arranged to draw the carbons together, thus starting the arc. The pull of the solenoid and that of the springs are adjusted to maintain the arc at its proper length.

Such lamps have the disadvantage of a high resistance at the start—450 ohms or more—and are difficult to start on series circuits, due to the high voltage required. They tend to maintain a constant voltage at the arc, but do not aid the dynamo in its regulation, so that the arcs are liable to be a little unsteady.

With the **Series-Lamp Mechanism,** the carbons are together when the lamp is first started and the current, flowing in the series coil, separates the electrodes, striking the arc. When the arc is too long, the resistance is increased and the current lowered so that the pull of the solenoid is weakened and the carbons feed together. This type of lamp can be used only on constant-potential systems.

Fig. 12 shows a diagram of the connection of such a lamp. This diagram is illustrative of the connection of one of the lamps manufactured by the Western Electric Company, for use with direct current on a constant-potential system. The symbols + and — refer to the terminals of the lamp, and the lamp must be so connected that the current flows from the top carbon to the bottom one. R is a series resistance, adjustable for different voltages by means of the shunt G. F and D are the controlling solenoids connected in series with the arc. B and C are the positive and negative carbons respectively, while A is the switch for turning the current on and off. H is the plunger of the solenoids and I the carbon clutch, this being what is known as a "carbon feed" lamp. The

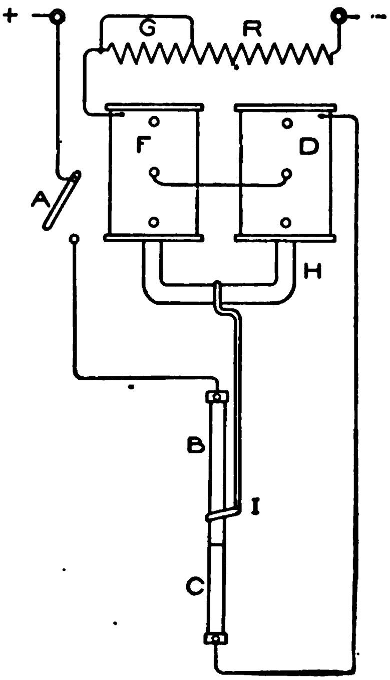


Fig. 12.

carbons are together when A is first closed, the current is excessive, and the plunger is drawn up into the solenoids, lifting the carbon B until the resistance of the arc lowers the current to such a value that the pull of the solenoid just counterbalances the weight of the plunger and carbon. G must be so adjusted that this point is reached when the arc is at its normal length.

In the **Differential Lamp**, the series and shunt mechanisms are combined, the carbons being together at the start, and the series coil arranged so as to separate them while the shunt coil is connected across the arc, as before, to prevent the carbons from being drawn too far apart. This lamp operates only over a low-current range, but it tends to aid the generator in its regulation.

Fig. 13 shows a lamp having a differential control, this also being the diagram of a Western Electric Company arc lamp for direct-current, constant-potential system. Here S represents the shunt coil and M the series coil, the armature of the two magnets A and A′ being attached to a bell-crank, pivoted at B, and attached to the carbon clutch C. The pull of coil S tends to lower the carbon while that of M raises the carbon, and the two are so adjusted that equilibrium is reached when the arc is of the proper length. All of the lamps are fitted with an air dashpot or some damping device to prevent too rapid movements of the working parts.

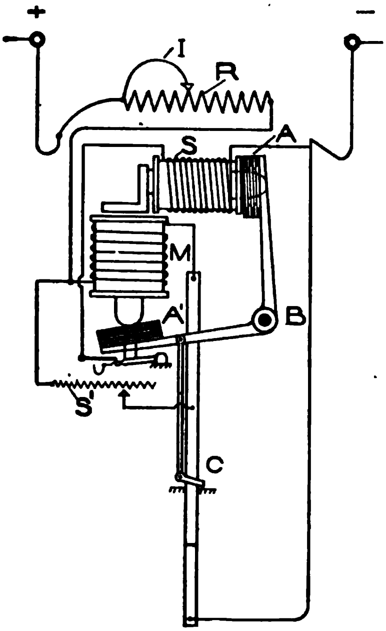


Fig. 13.

The methods of supporting the carbons and feeding them to the arc may be divided into two classes:

1. Rod feed.
2. Carbon feed.

Lamps using a **Rod Feed** have the upper carbons supported by a conducting rod, and the regulating mechanism acts on this rod, the current being fed to the rod by means of a sliding contact. Fig. 14 shows the arrangement of this type of feed. The rod is shown at R, the sliding contact at B, and the carbon is attached to the rod at C.

These lamps have the advantage that carbons, which do not have a uniform cross-section or smooth exterior, may be used, but they possess the disadvantage of being very long in order to accommodate the rod. The rod must also be kept clean so as to make a good contact with the brush.

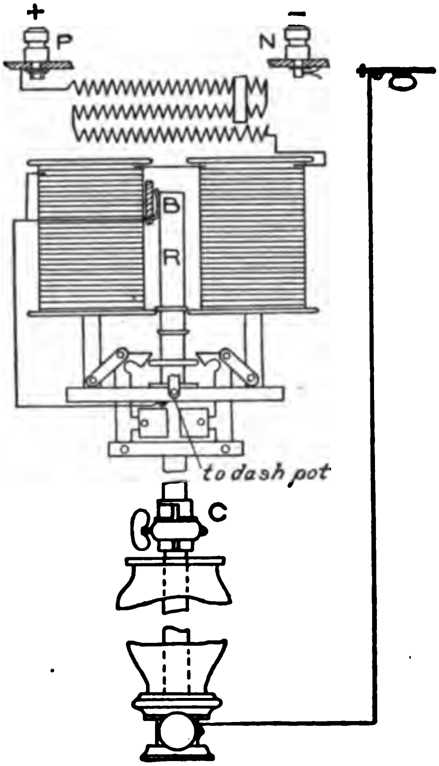


Fig. 14.

In **Carbon-Feed** lamps the controlling mechanism acts on the carbons directly through some form of clutch such as is shown at C in Fig. 15. This clamp grips the carbon when it is lifted, but allows the carbon to slip through it when the tension is released. For this type of feed the carbon must be straight and have a uniform cross-section as well as a smooth exterior. The current may be led to the carbon by means of a flexible lead and a short carbon holder.

Double-Carbon Lamps. In order to increase the life of the early form of arc lamp without using too long a carbon, the double-carbon type was introduced. This type uses two sets of carbons, both sets being fed by one mechanism so arranged that when one pair of the electrodes is consumed the other is put into service. With the introduction of the enclosed arcs, this form of lamp is rapidly disappearing, although a few are still in use.

Arc lamps are constructed to operate on *Direct Current* or *Alternating Current* systems when connected in *Series* or in *Multiple.* They are also made in both the *Open* and the *Enclosed* forms, but almost all of the lamps operating on alternating current or on constant-potential, direct current are enclosed.

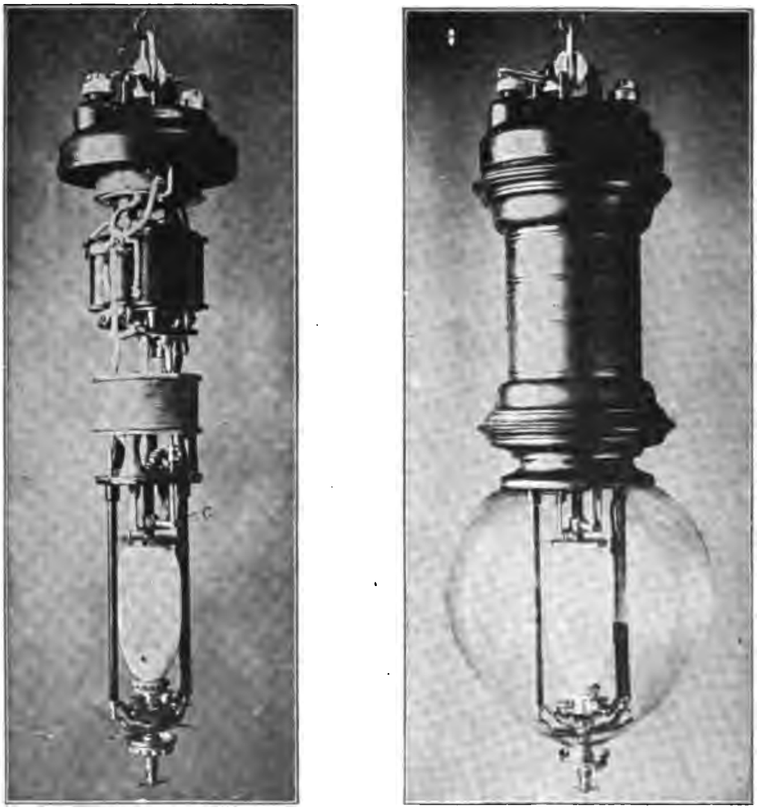
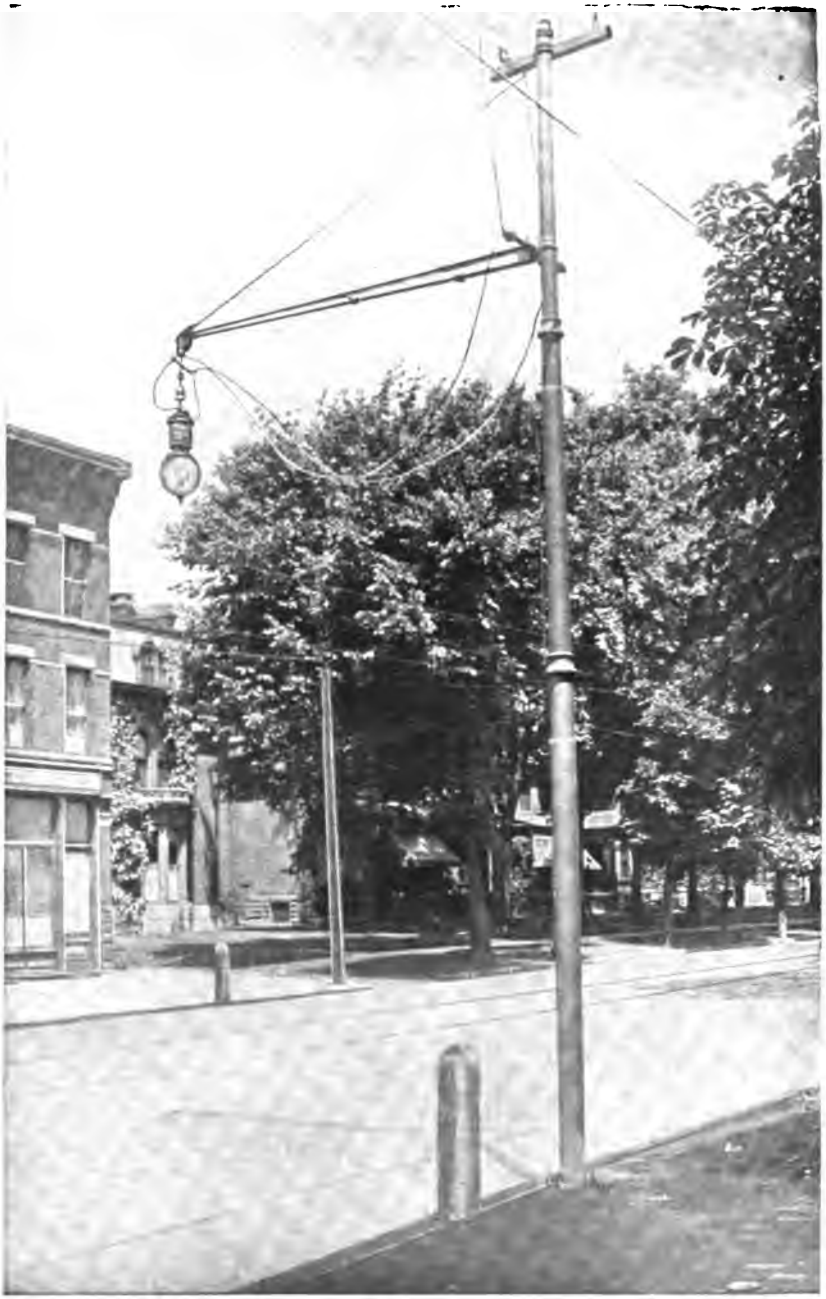


Fig. 15.

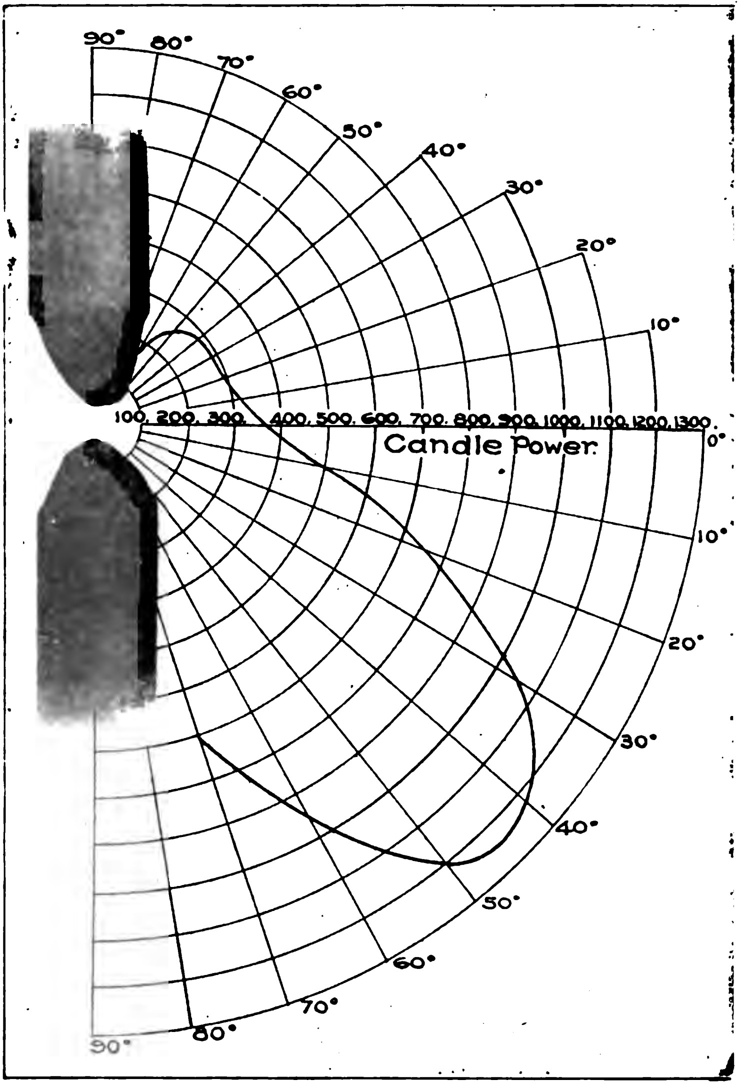
By an *Open Arc* is meant an arc lamp in which the arc is exposed to the atmosphere, while in the *Enclosed Arc* an inner or enclosing globe surrounds the arc, and this globe is covered with a cap which renders it nearly air-tight. Fig. 15 is a good example of an enclosed arc as manufactured by the General Electric Company.

Open Arcs for direct-current systems were the first to be used to any great extent, and they are used considerably at present,



MAST SUSPENSION OF ARC LAMPS.

General Electric Company.



DISTRIBUTION CURVE FOR ARC LAMP.

Fort Wayne Electric Works.

although they are being rapidly replaced by the enclosed types or the alternating-current systems. They are always connected in series, and are run from some form of special arc machine, a description of which may be found in "Types of Dynamo Electric Machinery".

Each lamp requires in the neighborhood of 50 volts for its operation, and, since the lamps are connected in series, the voltage of the system will depend on the number of lamps; therefore, the number of lamps that may be connected to one machine is limited by the maximum allowable voltage on that machine. By special construction as many as 125 lamps are run from one machine, but even this size of generator is not so efficient as one of greater capacity. Such generators are usually wound for 6.6 or 9.6 amperes. Since the carbons are exposed to the air at the arc, they are rapidly consumed, requiring that they be renewed daily for this type of lamp.

Enclosed Direct-Current Arc Lamps for series systems are constructed much the same as the open lamp, and are controlled by either shunt or differential mechanism. They require a voltage from 68 to 75 at the arc, and are usually constructed for from 5 to 6.8 amperes. They also require a constant-current generator.

Arc Lamps for Constant-Potential direct-current systems must have some resistance connected in series with them to keep the voltage at the arc at its proper value. This resistance is made adjustable so that the lamps may be used on any circuit. Its location is clearly shown in Fig. 15, one coil being located above, the other below the operating solenoids.

Arc Lamps for Alternating Currents do not differ greatly in construction from the direct-current arcs. When iron or other metal parts are used in the controlling mechanism, they must be laminated or so constructed as to keep down induced or eddy currents which might be set up in them. For this reason the metal spools, on which the solenoids are wound, are slotted at some point to prevent them from forming a closed secondary to the primary formed by the solenoid winding. On constant potential circuits a reactive coil is used in place of a part of the resistance for cutting down the voltage at the arc.

Interchangeable Arc Lamps are manufactured which may be readily adjusted so as to operate on either direct or alternating current, and on voltages from 110 to 220. Two lamps may be run in series on 220-volt circuits.

The distribution of light, and the resulting illumination for the different lamps just considered, will be taken up later. Aside from the distribution and quality of light, the enclosed arc has the advantage that the carbons are not consumed so rapidly as in the open lamp because the oxygen is soon exhausted from the inner globe and the combustion of the carbon is greatly decreased. They will burn from 80 to 100 hours without re-trimming.

TABLE 2.

D. C. Lamp.	Current.	Watts Consumed.			Mean Intensity in H. U.			Mean Watts.		
		In Lamp.	In Arc.	Mechanism.	Spherical.		Lower Hemi-spherical	Spherical H. U.		Lower Hemi-spherical
					Op. Outer.	Clear Outer	Clear Outer.	Op. Outer.	Clear Outer.	Clear Outer.
						235	332		2.37	1.66
1	5.01	551	401	150	172	256*	362*	3.10	2.18*	1.52*
2	5.08	559	406	252	195	216	282	2.85	2.60	1.99
4	4 76	524	381	143	127	139	208	4.12	3.76	2.52
5	4.76†	458	333	125	154	174	221	2.96	2.63	2.07
7	4.76	524	381	143	208	333	317	2.63	2.20	1.65
9	4.84	532	387	145	182	226	281	2.83	2.38	1.89
10	4.99	549	399	150	202	242	309	2.74	2.24	1.77
12	4.87	536	390	146	178	195	230	3.05	2.66	2.33
Mean	4.9	529	384	144	176	207	272	3.03	2.60	1.98

A. C. Lamp.	Current.	In Lamp.	Power Factor Lamp.	In Arc.	Power Factor Arc.	Mechanism.						
101	6.40	448	.63	340	.82	108	127	141	206	3.52	5.17	2.17
								208	236		2.26	1.94
102	6.79	459	.61	375	.78	84	146	176†	226†	3.31	2.60†	1 72†
103	5.89	424	.65	344	.75	80	116	130	147	3.66	3.15	2.88
105	6.20	414	.61	382	.80	32	128	187	219	3.24	2.20	1.89
								153	169		2.56	2.23
106	6.12	378	.56	298	.70	80	132	182†	284	2.82	2.19†	1.48†
108	6.48	457	.64	383	.80	74.5	133	175	211	3.20	2.61	2.16
110	6.18	339	.49	276	.72	63	140*	126	143	2.41*	2.68	2.37
Mean	6.29	417	.60	342	.76	74.5	130	159	190	3.31	2.66	2.23

*Condition of no outer globe. †Condition with shade on lamp. H. U Hefner Units.

Rating of Arc Lamps. Open arcs have been classified as follows:

Full Arcs, 2,000 candle-power taking 9.5 to 10 amps. or 450–480 watts.
Half Arcs, 1,200 candle-power taking 6.5 to 7 amps. or 325–350 watts.

These candle-power ratings are much too high, and run more nearly 1,200 and 700, respectively, for the point of maximum intensity and less than this if the mean spherical candle-power be taken. For this reason, the ampere or watt rating is now used to indicate the power of the lamp. Enclosed arcs use from 3 to 6.5 amperes, but the voltage at the arc is higher than for the open lamp. Table 2 gives some data on enclosed arcs on constant-potential circuits.

Efficiency. The efficiency of arc lamps is given as follows:

Direct Current Arc (enclosed) 2.9 watts per candle-power.
Alternating Current Arc (enclosed) 2.95 watts per candle-power.
Direct Current Arc (open) .6–1.25 watts per candle-power.

Arc-Lamp Carbons are either moulded or forced from a product known as petroleum coke or from similar materials such as lampblack. The material is thoroughly dried by heating to a high temperature, then ground to a fine powder and combined with some substance such as pitch which binds the fine particles of carbon together. After this mixture is again ground it is ready for moulding. The powder is put in steel moulds and heated until it takes the form of a paste, when the necessary pressure is applied to the moulds. For the forced carbons, the powder is formed into cylinders which are placed in machines which force the material through a die so arranged as to give the desired diameter. The forced carbons are often made with a core of some special material, this core being added after the carbon proper has been finished. The carbons, whether moulded or forced, must be carefully baked to drive off all volatile matter. The forced carbon is always more uniform in quality and cross-section, and is the type of carbon which must be used in the carbon feed lamp. The adding of a core of a different material seems to change the quality of light, and being more readily volatilized, keeps the arc from wandering.

Plating of carbons with copper is sometimes resorted to for moulded forms for the purpose of increasing the conductivity, and, by protecting the carbon near the arc, prolonging the life.

SPECIAL LAMPS.

Under this heading may be considered all lamps which do not use carbon as the incandescent material, as well as some lamps

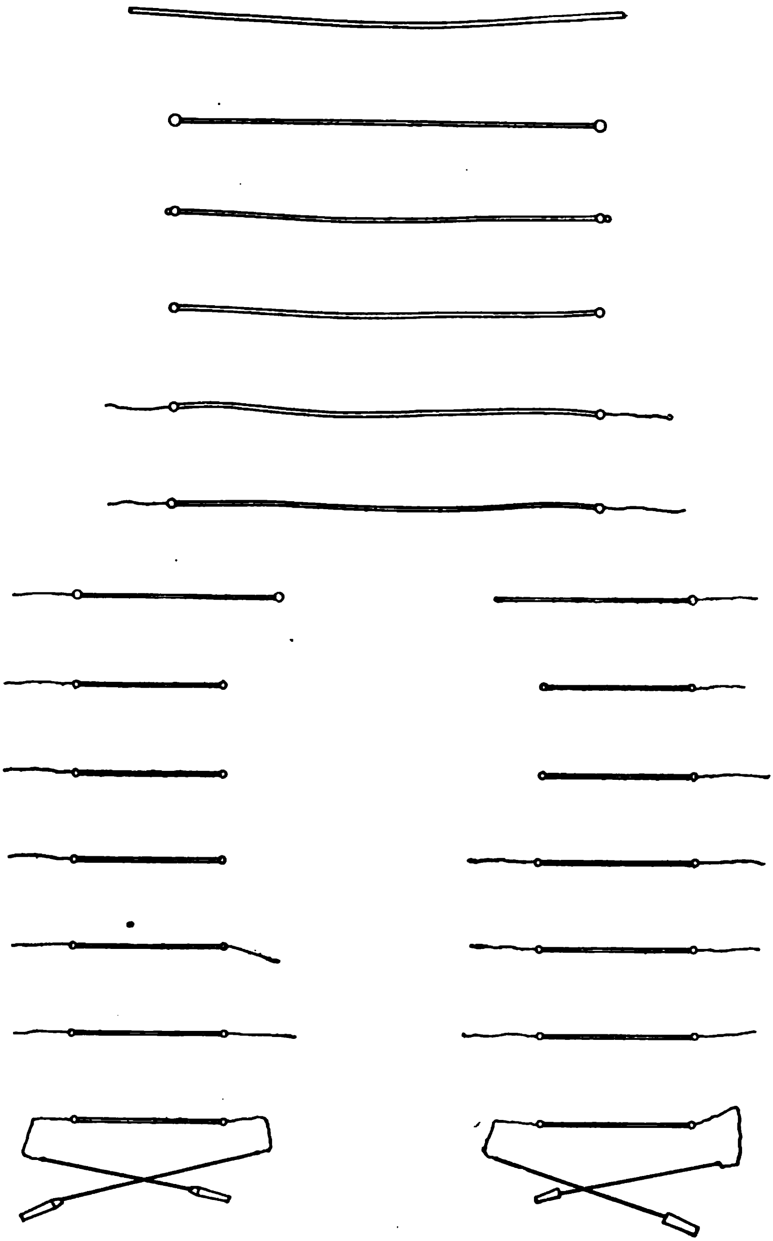


Fig. 16.

which use carbon in conjunction with other materials. The first of these lamps, or the one at present most widely used, is the Nernst Lamp.

The Nernst Lamp is an incandescent lamp using for the incandescent material certain oxides of the rare earths. The oxide is mixed in the form of a paste, then squirted through a die into a string which is subjected to a roasting process forming the filament or *glower* material of the lamp. The glowers are cut the desired length and platinum terminals attached. The attachment of these terminals to the glowers is a very important process in the manufacture of the lamp, and is accomplished by fusing the ends of the glower and the platinum lead into small beads, and, when the two are brought into contact, the platinum is sucked up into the glower head, forming a very neat and efficient connection. Fig. 16 shows several completed glowers.

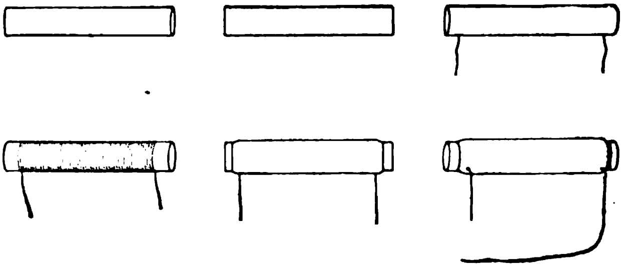


Fig. 17.

As the glower is a non-conductor when cold, some form of *heater* is necessary to bring it up to a temperature at which it will conduct. Two forms of heater are used, the first being formed of fine platinum wire wound over a porcelain tube as a support and covered with porcelain paste to prevent deterioration as much as possible. These "heater tubes", as they are called, are mounted just above the glowers in the finished lamp. The second form of heater is known as the "spiral heater", and this is also made of fine platinum wire wound on a porcelain rod and covered with paste, the rod being then formed on a mandrel to the desired shape. Figs. 17 and 18 show the two forms of heaters.

The heating device is connected across the circuit when the lamp is first turned on, and it must be cut out of circuit automatically when the glower becomes a conductor, otherwise the heater would soon be destroyed. This automatic *cut-out* is operated by means of an electromagnet so arranged that current flows through its coil as soon as the glower conducts and opens a form of silver contact cutting out the heater. The heater circuit is normally kept closed by the force of gravity so that the lamps will operate only in one position. A successful form of universal cut-out, that is, one which will operate when the lamp is in any position, has not yet been put on the market, though experiments with this type are being made.

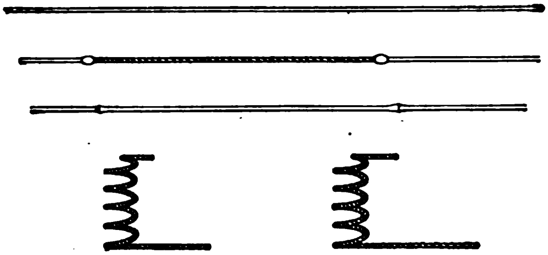


Fig. 18.

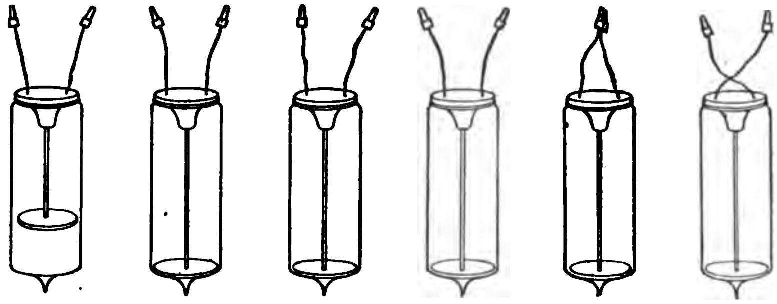


Fig. 19.

The conductivity of the glower increases with its temperature; hence, if used on a constant-potential circuit directly, its temperature would continue to increase, due to the greater current flowing, until the glower was destroyed. To prevent this increase of current, a *ballast resistance* of fine iron wire is connected in series with the glower. As is well known, the resistance of iron wire increases quite rapidly with increase of temperature, and this resistance is so adjusted that the resistance of the combined circuit reaches a constant value when the current is of the proper strength. The iron wire must be protected from the air to prevent oxidization and too rapid temperature changes, and, for this reason, it is mounted in a glass bulb filled with hydrogen. Hydrogen has been selected for this purpose because it is an inert gas and conducts the heat from the ballast to the walls of the bulb better than other gases. Fig. 19 shows the form of bulb which contains the ballast.

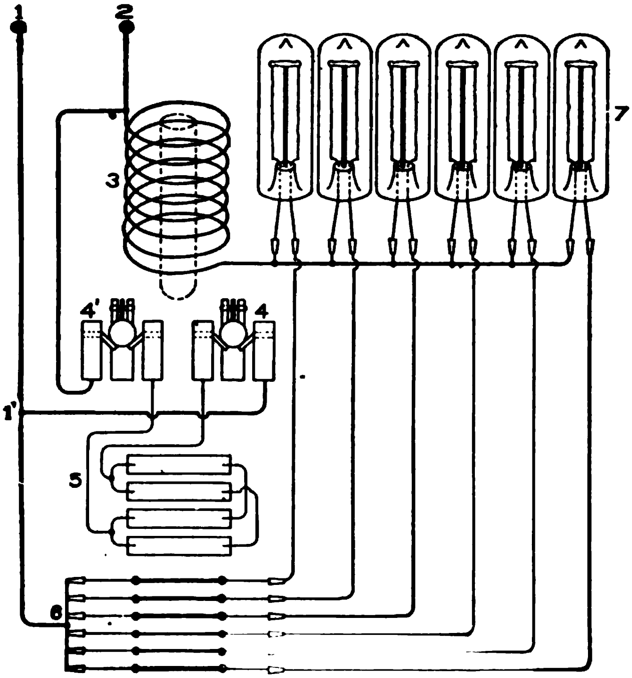


Fig. 20.

All of the parts enumerated, namely, glower, heater, cut-out and ballast, are mounted in a suitable manner, the smaller lamps having but one glower and arranged to fit an incandescent lamp socket, while the larger types have as many as six glowers and are arranged to be supported in a manner similar to arc lamps. All of the parts are interchangeable and may be easily renewed.

Fig. 20 shows the complete connections of a six-glower lamp. Current enters the lamp at terminal 1 (or 2), passes through the

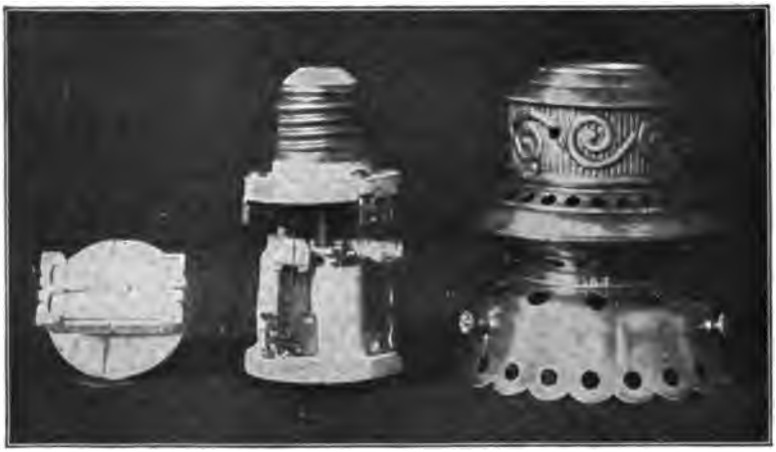


Fig. 21.

contacts of the cut-out 4, to the heater circuit 5, then to the contacts 4′ and to terminal 2. When the glowers become hot enough to conduct, the current divides at 1′, part of it going through the glowers 6, the ballast 7, and the cut-out coil 3 to terminal 2. By the time the current in the glower has reached its normal value, the contacts at 4 and 4′ have opened, cutting out the heater coils

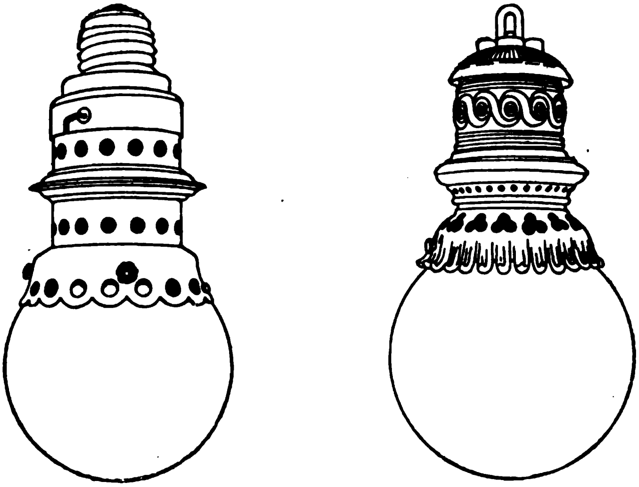


Fig. 23.

entirely. The heaters are so arranged that if one is destroyed, the other two will heat the glowers as quickly as possible.

Fig. 21 shows the parts of a single-glower lamp with the exception of the globe. Fig. 22 illustrates a six-glower street lamp. Fig. 23 shows lamps for inside use completely assembled. Fig. 24 shows a glower and spiral heater so mounted that the two may be very readily replaced. This type is used on some of the very latest forms of lamps put on the market by the Nernst Lamp Company of Pittsburg, which company controls the manufacture of these lamps in the United States.

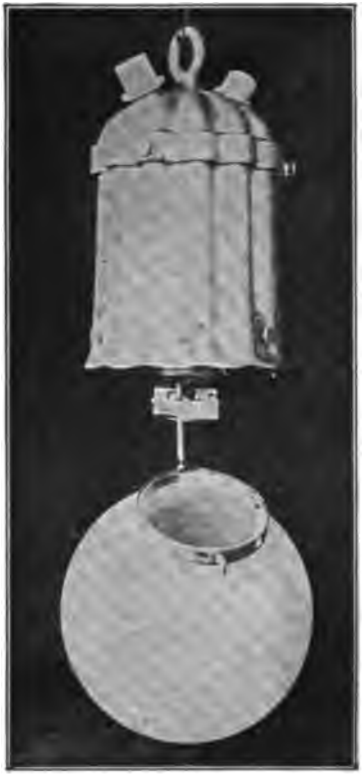


Fig. 22.

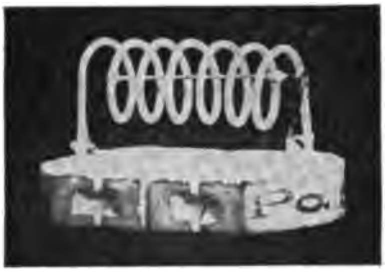


Fig. 24.

This type of lamp is used most extensively on alternating-current circuits at a frequency of about 60 cycles, and preferably at 220 volts, as the efficiency is better at this voltage, due to less energy being consumed in the ballast. Series lamps, and lamps operated on direct current, are now equally successful.

The advantages claimed for the Nernst lamp are increased efficiency, a good color of light, and a good light distribution. The efficiency varies with the type and the voltage used, as well as with the direction in which the candle-power is measured and the type of globe used. For a 100-hour run on a two-glower, 220-volt lamp using a 6-inch light sand-blasted globe, the watts varied from 170 to 158, while the mean hemispherical candle-power varied from 67.8 to 50.8, giving an efficiency from 2.5 to 3.1 watts per mean hemispherical candle-power; showing an efficiency better than the incandescent but not so good as the arc lamp.

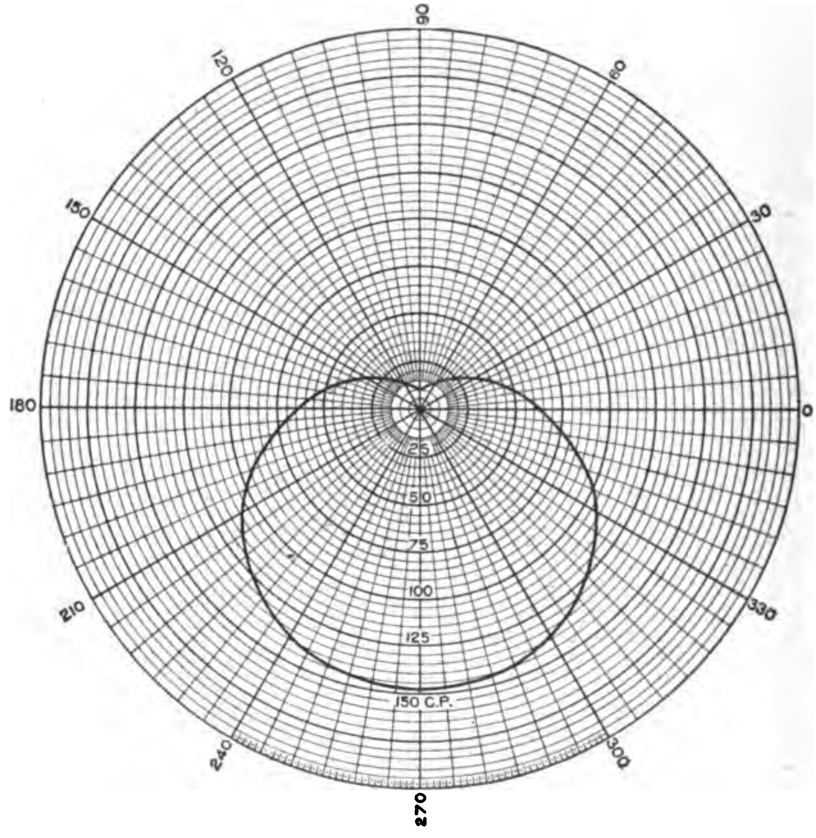
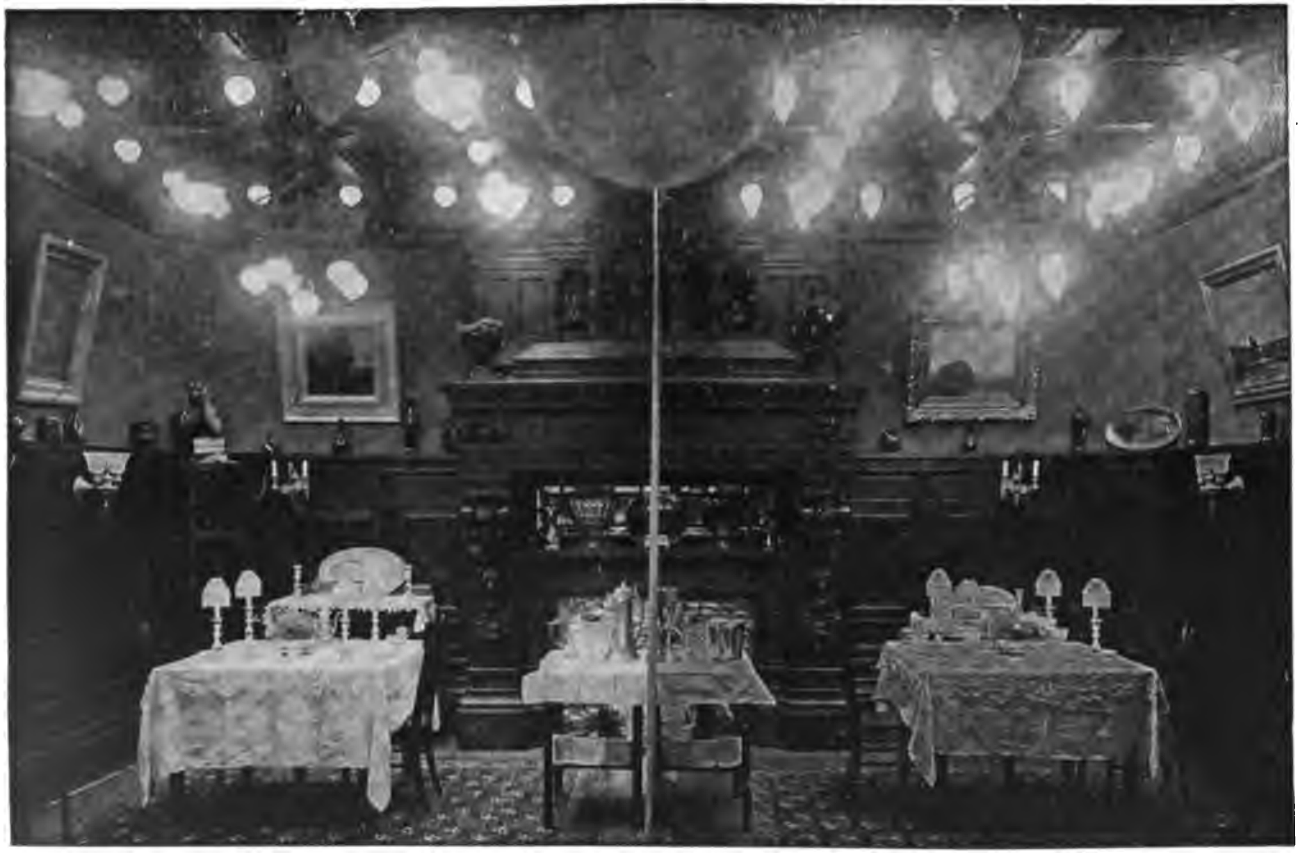


Fig. 25.

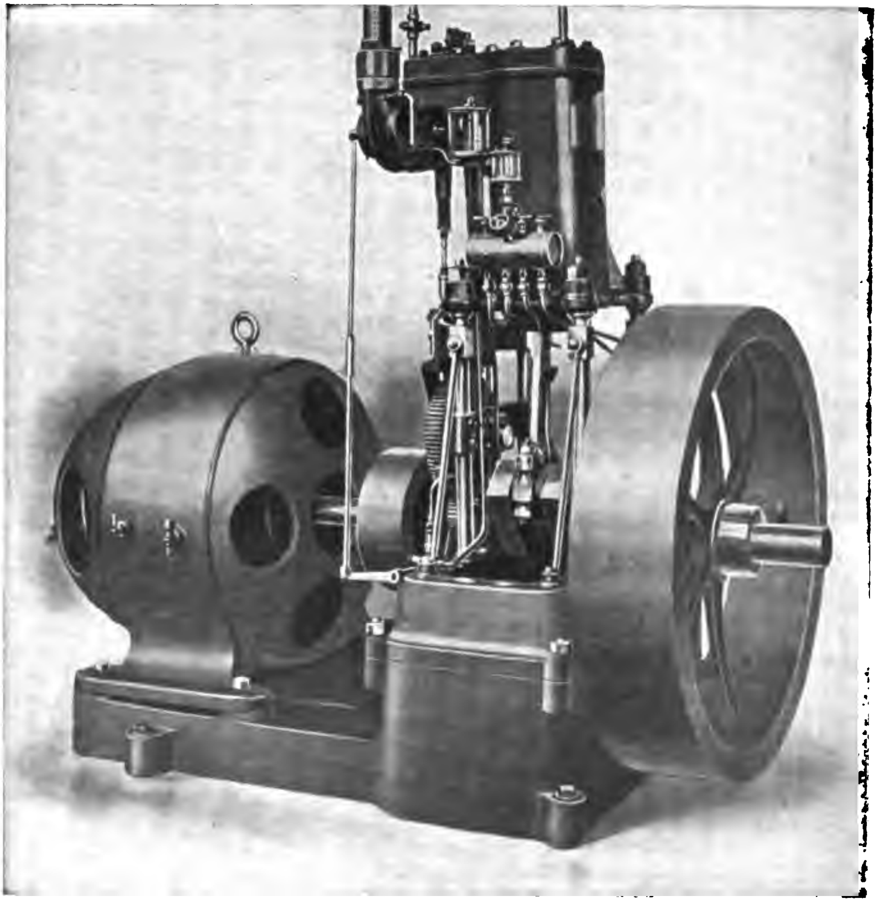
Fig. 25 shows two distribution curves for Nernst lamps.

To give the best results, lamps using the tube heaters must be cleaned regularly at the intervals of about 100 hours of burning. The spiral heaters are not cleaned, but are renewed at the end of the useful life of the glower. The light given by these lamps is very white in color, and the use of sand-blasted or alabaster globes reduces its intense brilliancy.



HOLOPHANE EXHIBIT.

World's Fair, St. Louis.



5 KILOWATT, 80 LIGHT.

Secor Oil-Electric Generating Plant.

Osmium Lamps. Osmium has been experimented on as a substance to replace carbon in the ordinary incandescent lamp, and so far very efficient lamps have been constructed using this material, but the voltage is low, due to the low resistance of the material and the difficulty of making a filament fine enough to give the desired resistance for higher voltages. At 25 volts, lamps are constructed giving an efficiency of 1.5 to 1.7 watts per candle-power, and with a life comparable with that of a 3.5-watt incandescent lamp. The low voltage makes this lamp undesirable for parallel distribution systems.

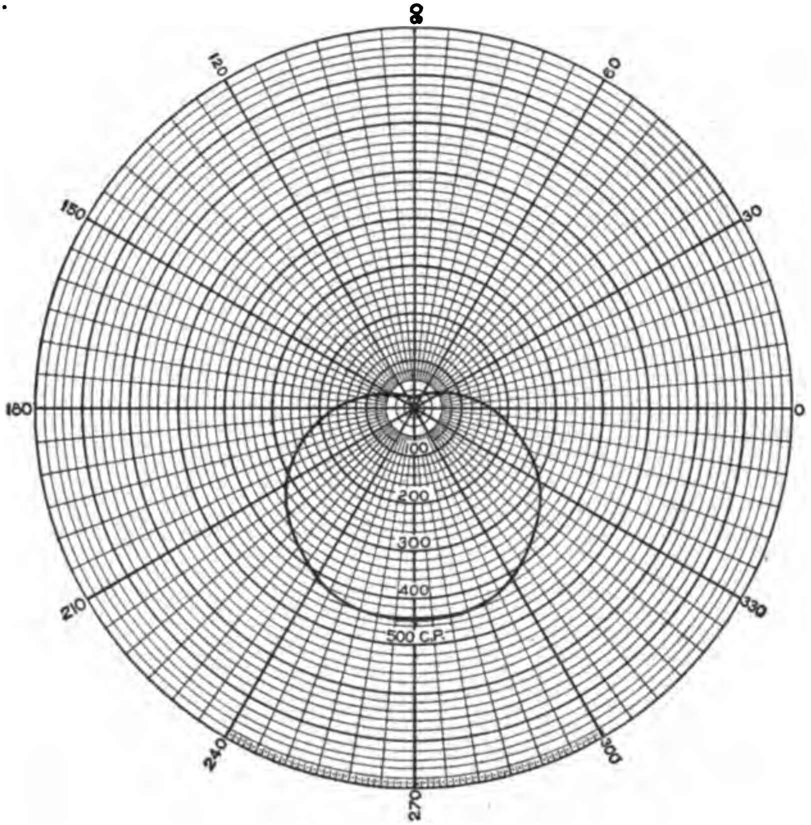


Fig. 25.

The Bremer Arc Lamp is one of the most favorable of several modifications of the arcs which have been proposed. This lamp uses very slender carbons having a core made of refractory oxides such as silica, lime, or magnesia. An efficiency of .1 to .4 watts per candle-power (mean spherical) has been claimed for this type of lamp, but it is still in the experimental stage.

The Mercury Vapor Lamp. Probably the Cooper Hewitt, or Mercury Vapor Lamp, is the only other special lamp deserving mention here. This lamp is being introduced to quite an extent where the quality of the light is not of so much importance. In this lamp, mercury vapor, rendered incandescent by the passage of an electric current, forms the source of light. One electrode is formed of mercury and the other may be of mercury or iron. In the more common type of lamp, these electrodes are mounted at the end of a long glass tube which has been very carefully exhausted. Fig. 26 shows such a lamp constructed for a 110-volt circuit. Dimensions of this lamp are as follows:

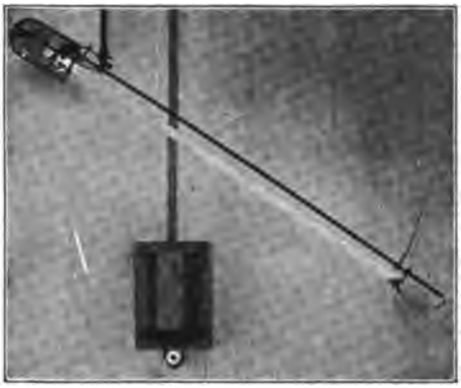


Fig. 26.

	For 100 Volts.	For 120 Volts.
Length of light-giving tube.......	43 inches.	49 inches.
Length over all..................	50 inches.	56 inches.
Diameter........................	1 inch.	

Current 3 to 3.5 amperes.
Candle Power at 120 volts, 750.
Life (average), 1,600 hours.

The mercury vapor, at the start, may be formed in two ways. First, the lamp may be tipped so that a stream of mercury makes contact between the two electrodes and mercury is vaporized when the stream breaks. Second, by means of a high inductance and a quick break switch; a very high voltage, sufficient to pass current from one electrode to the other, is induced and the conducting vapor formed. The lamp, as now manufactured, will operate only on direct current, but the alternating-current lamp is being developed.

Fig 27 is a diagram of a lamp connected for starting by the quick-break method, while Fig. 28 shows two 55-volt lamps connected in series on a 110-volt circuit, and arranged to be started by tipping. A steadying resistance and reactance are connected as shown in the diagram, the two being mounted on one base which may readily be attached to the wall as shown in Fig. 26.

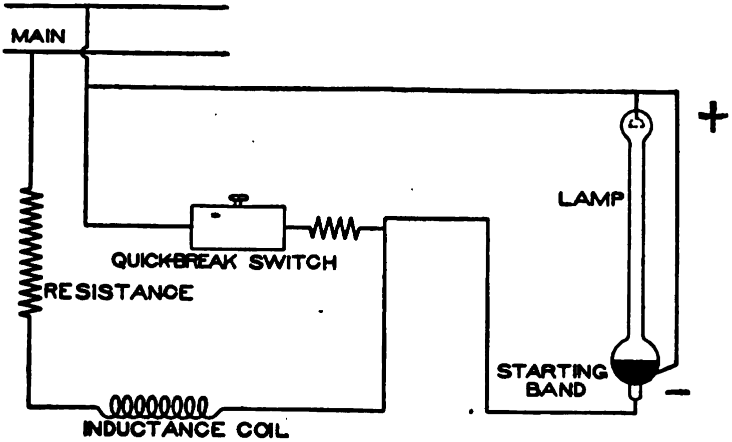


Fig. 27.

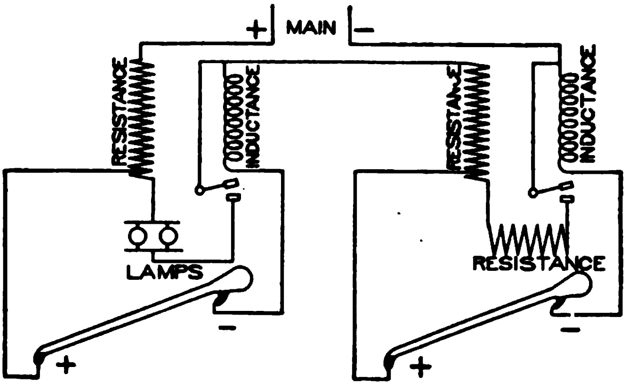


Fig. 28.

The mercury vapor lamp is not made in small sizes for ordinary voltages, and its light is very objectionable for the purpose of distinguishing color, as there is an entire absence of red rays.

This absence of the red light makes the illumination one that is very easy on the eyes but, on account of the color, its use is limited to the lighting of shops, offices, and drafting rooms, or in display windows where the goods shown are not changed in appearance by its color. It is also coming into use to a large extent in photographic work on account of the actinic properties of its light.

POWER DISTRIBUTION.

The question of power distribution for electric lamps and other appliances is taken up fully in the section on that subject, therefore it will be treated very briefly here. The systems may be divided into:

1. **Series Distribution Systems.**
2. **Multiple-Series or Series-Multiple Systems.**
3. **Multiple or Parallel Systems.**

They apply to both alternating and direct current.

The Series System is the most simple of the three; the lamps, as the name indicates, being connected in series as shown in Fig. 29. A constant load is necessary if a constant potential is to be used. If the load is variable, a constant-current generator, forms of which are described in "Types of Dynamo-Electric Machinery", or a special regulating device is necessary. Such devices are constant-current transformers and constant-current regulators as applied to alternating-current circuits.

The series system is used mostly for arc and incandescent lamps when applied to street illumination. Its advantages are simplicity and saving of copper. Its disadvantages are high voltage, fixed by the number of lamps in series; size of machines is limited since they cannot be insulated for voltage above about 6,000; a single open circuit shuts down the whole system.

Alternating-current series distribution systems are being used to a very large extent. By the aid of special transformers, or regulators, any number of circuits can be run from one machine or set of bus bars, and apparatus can be built for any voltage and of any size. It is not customary, however, to build transformers of this type having a capacity greater than 100, 6.6-ampere lamps.

The constant-current transformer most in use for lighting purposes is the one manufactured by the General Electric Company and commonly known as a "tub" transformer. Fig. 30 shows such a transformer when removed from the case, and Fig. 29 gives a diagram of the connection of a single-coil transformer in service.

Referring to Fig. 30, the fixed coils A form the primaries which are connected across the line; the movable coils B are the secondaries connected to the lamps. There is a repulsion of the coils B by the coils A when the current flows in both circuits and this force is balanced by means of the weights at W, so that the coils B take a position such that the normal current will flow in the secondary. On light loads, a low voltage is sufficient, hence the secondary coils are close together near the middle of the machine and there is a heavy magnetic leakage. When all of the lamps are on, the coils take the position shown when the leakage is a minimum and the voltage a maximum. When first starting up, the transformer is short-circuited and the secondary coils brought close together. The short circuit is then removed and the coils take a position corresponding to the load on the line.

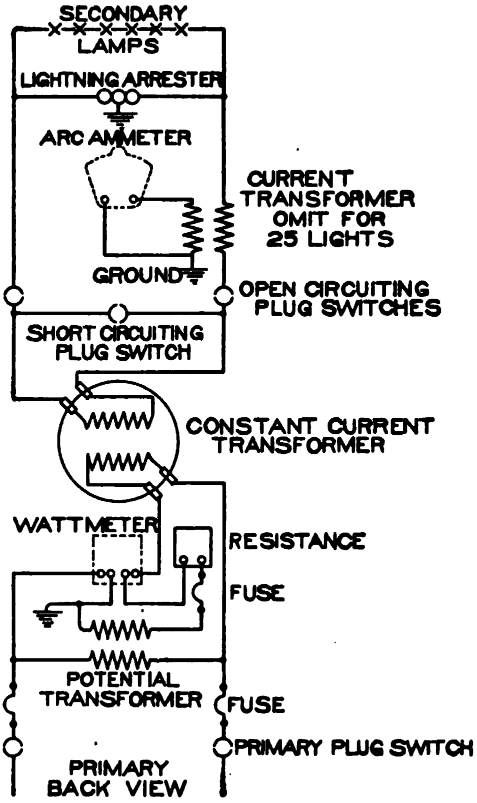


Fig. 29.

These transformers regulate from full load to $\frac{1}{3}$ rated load within $\frac{1}{10}$ ampere of normal current, and can be run on short circuit for several hours without overheating. The efficiency is given as 96% for 100-light transformers and 94.6% for 50-light transformers at full load. The power factor of the system is from

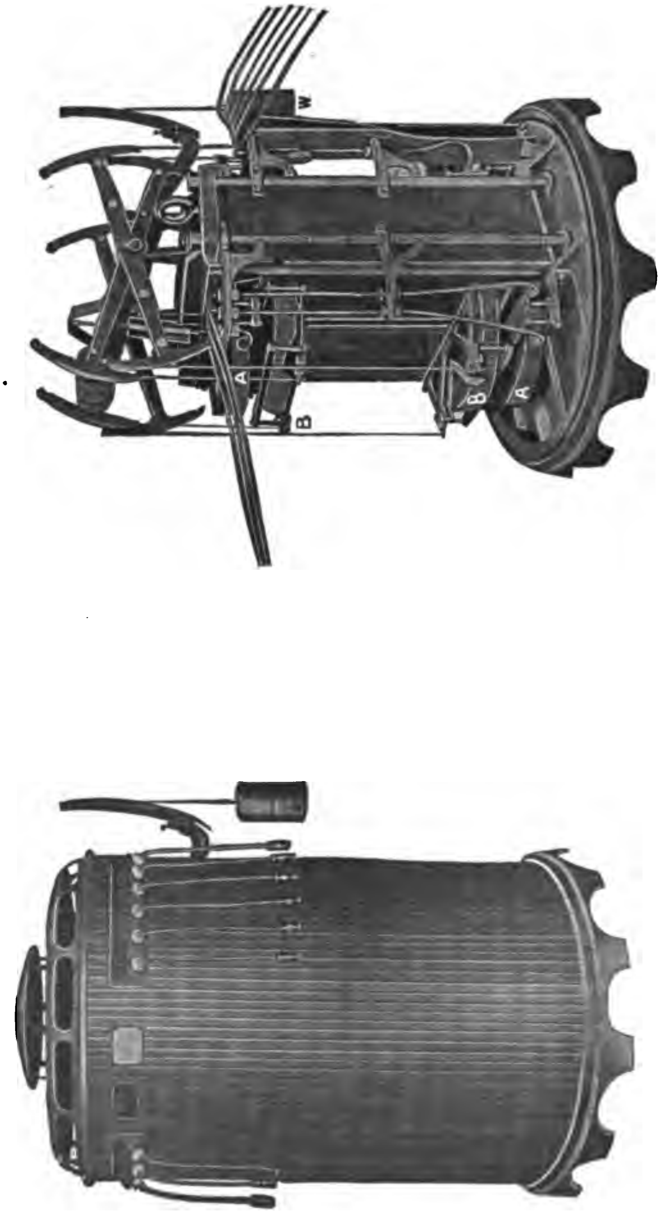


Fig. 30.

76 to 78% on full load, and, owing to the great amount of magnetic leakage at less than full load, the effect of leakage being the same as the effect of an inductance in the primary, the power factor is greatly reduced, falling to 62% at $\frac{3}{4}$ load, 44% at $\frac{1}{2}$ load, and 24% at $\frac{1}{4}$ load.

Standard sizes are for capacities of 25, 35, 50, 75, and 100, 6.6 ampere enclosed arcs. The low power factor of such a system on light loads shows that a transformer should be selected of such a capacity that it will be fully or nearly fully loaded at all times. The primary winding can be constructed for any voltage and the open circuit voltages of the secondaries are as follows:

25	light transformer,	2300 volts.
35	" "	3200 "
50	" "	4600 "
75	" "	6900 "
100	" "	9200 "

The 50-, 75-, and 100-light transformers are arranged for multiple circuit operation, two circuits used in multiple, and the voltages at full load reach 4,100 for each circuit on the 100-light machine.

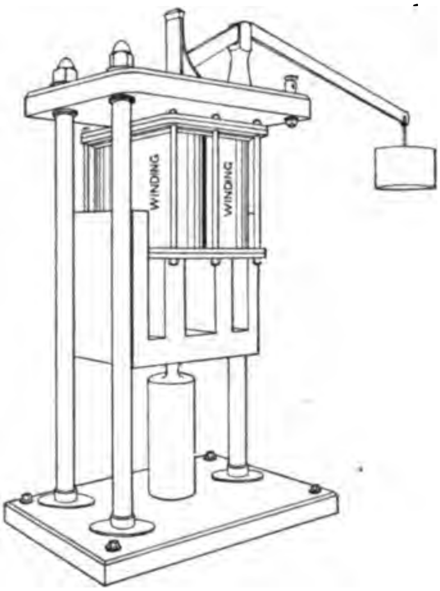


Fig. 31.

The second system, used for series distribution on alternating-current circuits, consists of a constant-potential transformer, stepping down the line voltage to that required for the total number of lamps on the system, allowing 83 volts for each lamp, and in series with the lamps is a reactive coil, the reactance of which is automatically regulated, as the load is increased or decreased, in order to keep the current in the line constant. Fig. 31 shows such a regulator as manufactured by the General Incandescent Arc Light Company, and Fig. 32 shows this regulator connected in circuit. The inductance is varied by the movement of the coil to include more or less iron in the magnetic circuit. Since the inductance in series with the lamps is high on light loads, the power factor is greatly reduced as in the constant-current transformer; and the circuits should, preferably, be run fully loaded. 60 to 65 lamps on a circuit is the maximum limit.

While used primarily for arc-light circuits, the same systems, designed for lower currents, are very readily applied to series incandescent systems.

Multiple-series and series-multiple systems combine several lamps in series and these groups in multiple, or several lamps in multiple and these groups in series, respectively. They have but a limited application.

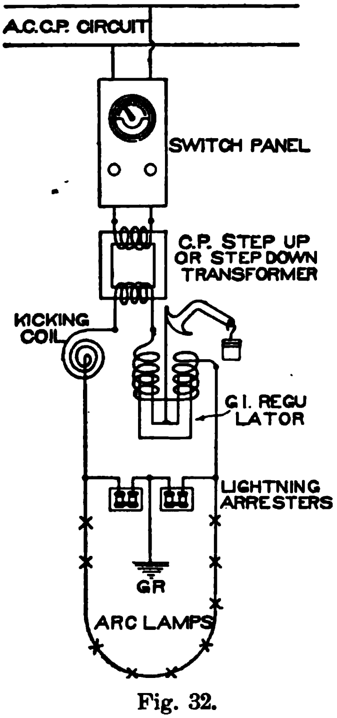


Fig. 32.

Multiple or Parallel Systems of Distribution. By far the largest number of lamps in service are connected to parallel systems of distribution. In this system, the units are connected across the lines leading to the bus bars at the station, or to the secondaries of constant-potential transformers. Fig. 33 shows a diagram of ten lamps connected in parallel. The current delivered by the machine depends directly on the number of lamps connected in service, the voltage of the system being kept constant.

Inasmuch as the flow of current in a conductor is always accompanied by a fall of potential equal to the product of the current flowing, into the resistance of the conductor, the lamps at the end of the system shown will not have as high a voltage impressed upon them as those nearer the machine. This drop in potential is the most serious obstacle that we have to overcome in multiple systems, and various schemes have been adopted to aid in this regulation. The systems may be classified as:

First, Cylindrical Conductors, parallel feeding.
Second, Conical " " "
Third, Cylindrical " anti-parallel feeding.
Fourth, Conical " " "

In the cylindrical conductor, parallel-feeding system, the conductors, A, B, C, D, Fig. 33, are of the same size throughout and are fed at the same end by the generator. The voltage is a minimum at the lamps E and a maximum at the lamps F; the value of the voltage at any lamp being readily calculated.

By a conical or tapering conductor is meant a conductor whose diameter is so proportioned throughout its length that the current, divided by the cross-section or the current density, is a constant quantity. Such a conductor is approximated in practice by using smaller sizes of wire as the current in the lines becomes less.

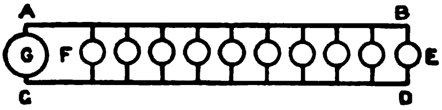


Fig. 33.

In an anti-parallel system, the current is fed to the lamps from opposite ends of the system as shown in Fig. 34.

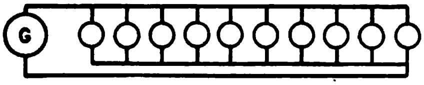


Fig. 34.

Multiple-Wire Systems. In order to take advantage of a higher voltage for distribution of power to the lighting circuits, three- and five-wire systems have been introduced, the three-wire system being used to a very large extent. In this system, three conductors are used, the voltage from each outside conductor and the middle neutral conductor being the same as for a simple parallel system. Fig. 35 gives a diagram of this. By this system the amount of copper required for a given number of lamps is from five-sixteenths to three-eighths of the amount required for a two-wire distribution, depending on the size of the neutral conductor. The saving of copper together with the disadvantages of the system is more fully treated in the paper on Power Transmission.

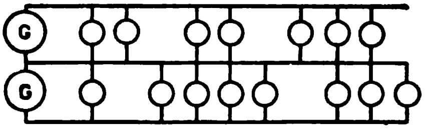


Fig. 35.

ILLUMINATION.

Illumination may be defined as the quality and quantity of light which aids in the discrimination of outline and the perception of color. Not only the quantity, but the quality of the light, as well as the arrangement of the units, must be considered in a complete study of the subject of illumination.

The Unit of Illumination is the *candle-foot* and its value is the amount of light falling on a surface at a distance of one foot from a source of light one candle-power in value. The law of inverse squares, namely, that the illumination from a given source varies inversely as the square of the distance from the source, shows that the illumination at a distance of two feet from a single candle-power unit is .25 candle-foot. For further consideration of the law of inverse squares, see "Photometry".

Illumination may be classified as *useful* illumination, when used for the ordinary purposes of furnishing light for carrying on work, taking the place of daylight, and *scenic* illumination. The latter applies to all forms of decorative lighting such as stage lighting, etc. The two divisions are not, as a rule, distinct, but the one is combined with the other.

Intrinsic Brightness. By intrinsic brightness is meant the amount of light emitted per unit surface of the light source. Table 3 gives the intrinsic brightness of several light sources.

TABLE 3.

Intrinsic Brilliancies in Candle-Power per Square Inch.

Source	Brilliancy	Notes.
Sun in zenith	600,000	Rough equivalent values, taking account of absorption.
Sun at 30 degrees elev.	500,000	
Sun on horizon	2,000	
Arc light	10,000 to 100,000	Maximum about 200,000 in crater.
Calcium light	5,000	
Nernst "glower"	1,000	Unshaded.
Incandescent lamp	200–300	Depending on efficiency.
Enclosed arc	75–100	Opalescent inner globe.
Acetylene flame	75–100	
Welsbach light	20 to 25	
Kerosene light	4 to 8	Variable.
Candle	3 to 4	
Gas flame	3 to 8	Variable.
Incandescent (frosted)	2 to 5	
Opal shaded lamps, etc.	0.5 to 2	

Regular Reflection. Regular reflection is the term applied to reflection of light when the reflected rays are parallel. It is of such a nature that the image of the light source is seen in the reflection. The reflection from a plane mirror is an example of this. It is useful in lighting in that the direction of light may be changed without complicating calculations aside from deductions necessary to compensate for the small amount of light absorbed.

Irregular Reflection, or diffusion, consists of reflection in which the reflected rays of light are not parallel but take various directions, thus destroying the image of the light source. Rough, unpolished surfaces give such reflection. Smooth, unpolished surfaces generally give a combination of the two kinds of reflection. Diffused reflection is very important in the study of illumination inasmuch as diffused light plays an important part in the lighting of interiors. This form of reflection is seen in many photometer screens. Light is also diffused when passing through semi-transparent shades or screens.

In considering reflected light, we find that, if the surface on which the light falls is colored, the reflected light may be changed in its nature by the absorption of some of the colors. Since, as has been said, in interior lighting the reflected light forms a large part of the source of illumination, this illumination will depend upon the nature and color of the reflecting surfaces.

Whenever light is reflected from a surface, either by direct or diffused reflection, a certain amount of light is absorbed by the surface. Table 4 gives the amount of white light reflected from different materials.

TABLE 4.

Material.	
White blotting paper	.82
White cartridge paper	.80
Chrome yellow paper	.62
Orange paper	.50
Yellow wall paper	.40
Light pink paper	.36
Yellow cardboard	.30
Light blue cardboard	.25
Emerald green paper	.18
Dark brown paper	.13
Vermilion paper	.12
Blue-green paper	.12
Black paper	.05
Black cloth	.012
Black velvet	.004

From this table it is seen that the light-colored papers reflect the light well, but of the darker colors only yellow has a comparatively high coefficient of reflection. Black velvet has the lowest value, but this only holds when the material is free from dust. Rooms with dark walls require a greater amount of illuminating power, as will be seen later.

Useful illumination may be considered under the following heads:

1. Residence Lighting.
2. Lighting of Public Halls, Offices, Drafting Rooms, Shops, etc.
3. Street Lighting.

RESIDENCE LIGHTING.

Type of Lamps. The lamps used for this class of lighting are limited to the less powerful units, namely, incandescent or Nernst lamps varying in candle-power from 8 to 32 per unit. These should always be shaded so as to keep the intrinsic brightness low. The intrinsic brilliancy should seldom exceed 2 to 3 candle-power per square inch, and its reduction is usually accomplished by appropriate shading. Arc lights are so powerful as to be uneconomical for small rooms, while the color of the mercury-vapor light is an additional objection to its use.

Plan of Illumination. Lamps may be selected and so located as to give a brilliant and fairly uniform illumination in a room; but this is an uneconomical scheme, and the one more commonly employed is to furnish a uniform, though comparatively weak, ground illumination, and to reinforce this at points where it is necessary or desirable. The latter plan is satisfactory in almost all cases and the more economical of the two.

While the use of units of different power is to be recommended, where desirable, lights differing in color should not be used for lighting the same room. As an exaggerated case, the use of arc with incandescent lamps might be mentioned. The arcs being so much whiter than the incandescent lamps, the latter appear distinctly yellow when the two are viewed at the same time.

Calculation of Illumination. In determining the value of illumination, not only the candle-power of the units, but the amount of reflected light must be considered for the given location of the lamps. Following is a formula based on the coefficient of reflection of the walls of the room, which serves for preliminary calculations:

$$I = \frac{c.p. \frac{1}{1-k}}{d^2}$$

I = Illumination in candle-feet.
$c.p.$ = Candle-power of the unit.
k = Coefficient of reflection of the walls.
d = distance from the unit in feet.

Where several units of the same candle-power are used this formula becomes

$$I = c.p. \left(\frac{1}{d^2} + \frac{1}{d_1^2} + \frac{1}{d_2^2} + \text{---------}\right) \frac{1}{1-k}$$

or,
$$c.p. = \frac{I}{\left(\frac{1}{d^2} + \frac{1}{d_1^2} + \frac{1}{d_2^2} + \text{---------}\right) \frac{1}{1-k}}$$

where d, d_1, d_2, etc., equal the distances from the point considered to the various light sources. If the lamps are of different candle-power, the illumination may be determined by combining the illumination from each source as calculated separately. An example of calculation is given under " Arrangement of Lamps ".

It is readily seen that the effect of reflected light from the ceilings is of more importance than that from the floor of a room. The value of k, in the above formula, will vary from 60% to 10%, but for rooms with a fairly light finish 50% may be taken as a good average value.

The amount of illumination will depend on the use to be made of the room. One candle-foot gives sufficient illumination for easy reading, when measured normal to the page, and probably an illumination of .5 candle-foot on a plane 3 feet from the floor forms a sufficient ground illumination. The illumination from sunlight reflected from white clouds is from 20 candle-feet up, while that due to moonlight is in the neighborhood of .03 candle-foot. It is not possible to produce artificially a light equivalent to daylight on account of the great amount of energy that would be required and the difficulty of obtaining proper diffusion.

Arrangement of Lamps. An arrangement of lamps giving a uniform illumination cannot be well applied to residences on account of the number of units required, and the inartistic effect. We are limited to chandeliers, side lights, or ceiling lights, in the majority of cases, with table or reading lamps for special illumination.

When ceiling lamps are used and the ceilings are high, some form of reflector or reflector lamp is to be recommended. In any case where the coefficient of reflection of the ceilings is less than 40%, it is more economical to use reflectors. When lamps are mounted on chandeliers, the illumination is far from uniform, being a maximum in the neighborhood of the chandelier and a minimum at the corners of the room. By combining chandeliers with side lights it is generally possible to get a satisfactory arrangement of lighting for small or medium-sized rooms.

As a check on the candle-power in lamps required, we have the following:

For brilliant illumination allow one candle-power per two square feet of floor space. In some particular cases, such as ball rooms, this may be increased to one candle-power per square foot.

For general illumination allow one candle-power for four square feet of floor space, and strengthen this illumination with the aid of special lamps as required. The location of lamps and the height of ceilings will modify these figures to some extent.

As an example of the calculation of the illumination of a room with different arrangements of the units of light, assume a room 16 feet square, 12 feet high, and with walls having a coefficient of reflection of 50%. Consider first the illumination on a plane 3 feet above the floor when lighted by a single group of lights mounted at the center of the room 3 feet below the ceiling. If a minimum value of .5 candle-foot is required at the corner of the room we have the equation

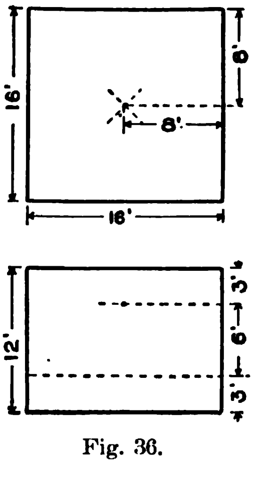


Fig. 36.

$$.5 = c.p. \frac{1}{12.8^2} \times \frac{1}{1 - .5}$$

Since $d = \sqrt{8^2 + 8^2 + 6^2} = 12.8$ (see Fig. 36)

Solving the above for the value of *c.p.*, we have

$$c.p. = \frac{.5}{\frac{1}{164} \times \frac{1}{.5}} = .5 \times 82 = 41$$

Three 16-candle-power lamps would serve this purpose very well.

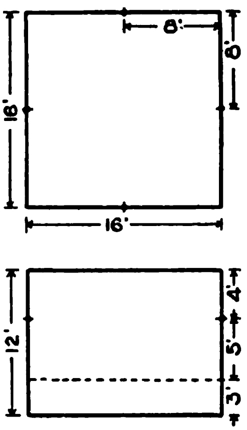


Fig. 37.

Determining the illumination directly under the lamp, we have:

$$I = 48 \times \frac{1}{6^2} \times \frac{1}{1 - .5} = \frac{48}{36} \times 2 =$$

2.7 candle-feet, or five times the value of the illumination at the corners of the room.

Next consider four 8-candle-power lamps located on the side walls 8 feet above the floor as shown in Fig. 37. Calculating the illumination at the center of the room on a plane three feet above the floor, we have:

$$I = 8(\frac{1}{89} + \frac{1}{89} + \frac{1}{89} + \frac{1}{89}) \frac{1}{1 - .5}$$

$$d^2 = 8^2 + 5^2 = 64 + 25 = 89$$

$$I = 8 \times \frac{4}{89} \times 2 = .72 \text{ candle-foot.}$$

The illumination at the corner of the room would be:

$$I = 8(\frac{1}{89} + \frac{1}{89} + \frac{1}{345} + \frac{1}{345}) \frac{1}{1 - .5}$$

$$= 8(\frac{2}{89} + \frac{2}{345}) \times 2 = .45 \text{ candle-foot.}$$

In a similar manner the illumination may be calculated for any point in the room, or a series of points may be taken and curves plotted showing the distribution of the light, as well as the areas having the same illumination. Where refined calculations are desired, the distribution curve of the lamp must be used for deter-

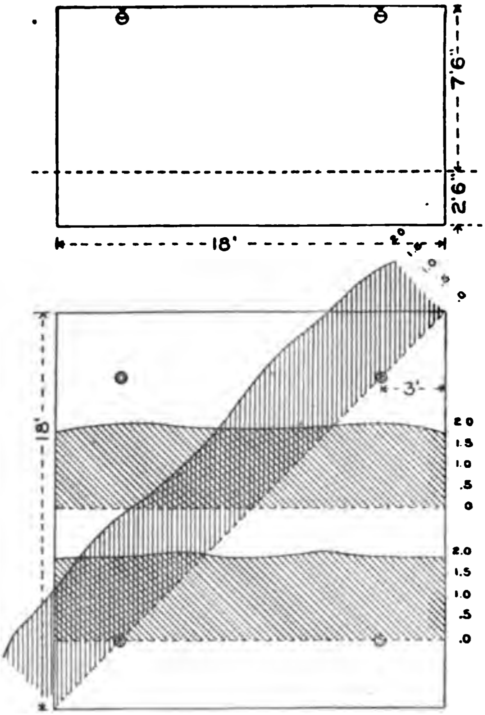


Fig. 38.

mining the candle-power in different directions. Fig. 38 shows illumination curves for the Meridian lamp manufactured by the General Electric Company. This is a form of reflector lamp made in two sizes, 25 or 50 candle-power. Fig. 39 gives the distribution curves for the 50-candle-power unit. Similar incandescent lamps are now being manufactured by other companies.

Table 5 gives desirable data in connection with the use of the Meridian lamp.

By means of the Weber, or some other form of portable photometer, curves as plotted from calculations may be readily checked after the lamps are installed. When lamps are to be permanently located, the question of illumination becomes an

TABLE 5.

Illuminating Data for Meridian Lamps.

Class Service.	Light Intensity in Candle-feet.	No. 1 Lamp (60 Watts)		No. 2 Lamp (120 Watts)		Watts per Sq. Ft. of Area Lighted With Either Lamp.
		Height of Lamp and Diameter of Uniformly Lighted Area.	Distance Between Lamps When Two or More are Used.	Height of Lamp and Diameter of Uniformly Lighted Area.	Distance Between Lamps When Two or More are Used.	
Desk or Reading Table.	3	2.9 feet.	4.9 feet.	4 feet.	7 feet.	2.50
	2	3.5 "	6 "	5 "	8.5 "	1.66
	1½	4 "	7 "	5.75 "	9.8 "	1.25
General Lighting.	1	5 "	8.5 "	7 "	12 "	0.83
	¾	5.75 "	9.8 "	8.2 "	13.9 "	0.62
	½	7 "	12 "	10 "	11 "	0.41

important one, and it is customary to determine, by calculation, the illumination curves and the isophotals, Fig. 38, as the lines showing equal illumination are called, for each room before installing the lamps. This applies to the lighting of large interiors more particularly than to residence lighting.

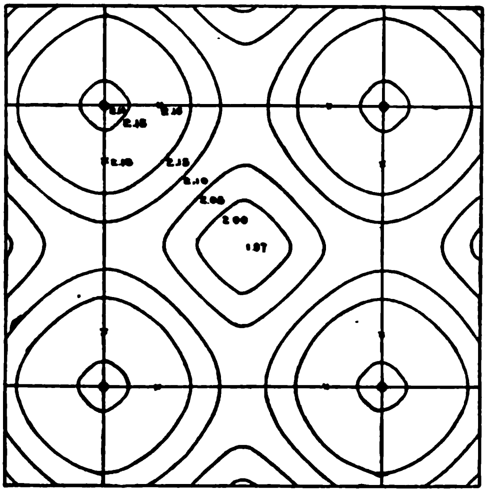


Fig. 38.

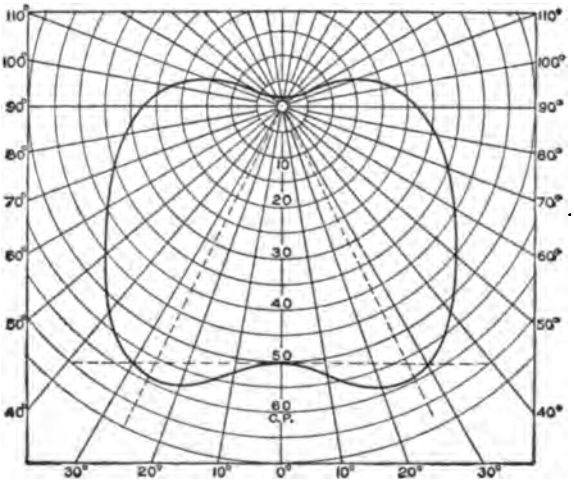


Fig. 39.

Dr. Louis Bell gives the following in connection with residence lighting:

TABLE 6.

Room.	8 c.p.	16 c.p.	32 c.p.	Sq. ft. per c.p.	Remarks.
Hall, 15′ × 20′	8			4.7	
Library, 20′ × 20′	12		1	3.1	8-c.p. reflector lamps.
Reception room, 15′ × 15′	4			7.0	
Music room, 20′ × 25′	12		2	3.0	
Dining room, 15′ × 20′	14			2.7	8 reflect'r lamps
Billiard room, 15′ × 20′			4	2.3	32-c.p. with reflectors.
Porch			1		
Bedrooms (6), 15′ × 15′		14		7.0	
Dressing rooms (2), 10′ × 15′		4		4.7	
Servants' rooms (3), 10′ × 15′		3		9.4	
Bathrooms (3), 8′ × 10′		3		5.0	
Kitchen, 15′ × 15′ Pantry, 10′ × 15′		3			
Halls Cellar	10	3			
Closets (4)	4				Reflector lamps
Total	64	30	8		

LIGHTING OF PUBLIC HALLS, OFFICES, ETC.

Lighting of public halls and other large interiors differs from the illumination of residences in that there is usually less reflected light, and, again, the distance of the light sources from the plane of illumination is generally greater if an artistic arrangement of the lights is to be brought about. This in turn reduces the direct illumination. The primary object is, however, as in residence lighting, to produce a fairly uniform ground illumination and to superimpose a stronger illumination where necessary. An illlumination of .5 candle-feet for the ground illumination may be taken as a minimum.

In the lighting of large rooms it is permissible to use larger light units, such as arc lamps and high candle-power Nernst or incandescent units, while for factory lighting and drafting rooms, where the color of the light is not so essential, the Cooper Hewitt lamp is being introduced. High candle-power reflector lamps, such as the Meridian lamp, are being used to a large extent for offices and drafting rooms.

The choice of the type of lamp depends on the nature of the work. Where the light must be steady, incandescent or Nernst lamps are to be preferred to the arc or vapor lamps, though the latter are often the more efficient. When arcs are used, they must be carefully shaded so as to diffuse the light, doing away with the strong shadows due to portions of the lamp mechanism, and to reduce the intrinsic brightness. Such shading will be taken up under the heading "Shades and Reflectors". Arcs are preferable to incandescent lamps when colored objects are to be illuminated, as in stores and display windows.

In locating lamps for this class of lighting, much depends on the nature of the building and on the degree of economy to be observed. For preliminary determination of the location of groups, or the illumination when certain arrangement of the units is assumed, the principles outlined under "Residence Lighting" may be applied. It has been found that actual measurements show results approximating closely such calculated values.

When arcs are used they should be placed fairly high, twenty to twenty-five feet when used for general illumination and the ceilings are high. They should be supplied with reflectors so as to utilize the light ordinarily thrown upwards. When used for drafting-room work, they should be suspended from twelve to fifteen feet above the floor, and special care must be taken to diffuse the light.

Incandescent lamps may be arranged in groups, either as side lights or mounted on chandeliers, or they may be arranged as a frieze running around the room a few feet below the ceiling. The last named arrangement of lights is one that may be made artistic, but it is uneconomical and when used should serve for the ground illumination only. Reflector lights may be used for this style of work and the lights may be entirely concealed from view, the reflecting property of the walls being utilized for distributing the light where needed.

Ceiling lights should preferably be supplied with reflectors, especially when the ceilings are high.

Measurements taken in well-lighted rooms having a floor space of from 1,000 to 5,000 square feet show an average of 3 to 3.5 square feet per candle-power. About 2.5 square feet per candle-power should be allowed when brilliant lighting is required or the ceilings are very high, while 3.75 square feet per candle power

TABLE 7.

Lighting Data for Arc Lamps.

Place Lighted.	Clothing Store.	Weave Room.	Erecting Room.	Machine Shop.	Drafting Room.	Drafting Room.	Ship Shed.	Cataloging Dept.	Jewelry Store.
No. of sq. ft. place lighted...	4000	14400	281600	42250	6275	5690	69000	4136	4000
No. lamps used...............	12	50	200	42	27	24	50	17	6
Circuit........................	A. C. Mult.	D. C. Mult.	D. C. Mult.	D. C. Mult.	A. C. Series.	D. C. Mult.	*D. C. Mult.	D. C. Mult.	D. C. Mult.
Cycles.........................	60	......	......	......	60	......	......	......	......
Volts line.....................	104	110	120	120	......	120	220	110	110
Amperes.......................	6	3¼	6.2	6.2	7.5	4	6	4½	5
Volts at arc..................	72	75	80	80	72	80	80	80	80
Power factor of lamp........	.69	......	......	......	.86	......	......	......	......
Watts per lamp...............	430	357	744	744	490	480	660	495	550
Watts per sq. ft. (term.).....	1.29	1.24	.53	.74	2.11	2.02	.478	2.03	.825
Kw. at term. (whole installation)	5.16	17.8	148.8	31.25	13.23	11.52	33	8.42	3.3
Kw. at arc (whole installation)	4.62	12.28	99.2	20.8	12.42	7.68	24	6.12	2.4
Sq. ft. lighted per lamp......	333	288	1408	1006	233	237	1380	243	667
Sq. ft. lighted per amp.......	55.6	88.6	227	162	31	59.3	230	54.1	133.5
Enclosing globe.............	Opal		Opal.	Opal.	Opal.	Opal.		Opal.	Opal.
Height and style of ceiling..	12' white steel.	Saw Toothed.	Trussed.	Trussed.	12' White.	Trussed.	160' Trussed.	13' 9" Maroon.	16' 10' White.
Reflector system used.......	Concentric Diffuser.	Adjust. Diffuser.	9" Mirror.	9" Mirror.	Concentric Diffuser.	16 Adj. Dif. 8 Con. Dif.	12" Mirror.	Concentric Diffuser.	Concentric Diffuser.
Height of arc from floor.....	9' 6"	12' to 15'	46'	47'	9'	15'	150'	10' 7"	13' 2"
Distance between lamps.....	14' to 18'	24'	32' to 38'	30' 9"	15'	12' to 25'	17' to 20'	14' to 18'	16' to 25'

will give good illumination when lights are well distributed and there is considerable reflected light.

In factory and drafting room lighting, the lamps must be arranged to give a strong light where most needed, and located to prevent such shadows as would interfere with the work.

Following are tables showing the number and distribution of arc and mercury-vapor lamps for lighting large rooms. Table 7 refers to arc lights as actually installed.

TABLE 8.

Lighting Data for Cooper-Hewitt Lamps.

Drafting Room.	2,140 sq. ft.	8 V-5 lamps.
	265 sq. ft. per lamp.	8 × 3.3 amperes = 26.5 amp.
	voltage 110.	80 sq. ft. per amp.
Office.	1,100 sq. ft.	3 H-4 lamps.
	366 sq. ft. per lamp.	3x3.3 amp. = 10 amp.
	voltage 110.	110 sq. ft. per amp.
Factory.	12,000 sq. ft.	30 V-4 lamps.
	400 sq. ft. per lamp.	30x1.7 amp. = 51 amp.
	voltage 110.	

STREET LIGHTING.

In studying the lighting of streets and parks, we find that, except in special cases, such as narrow streets and high buildings, there is no reflected light which aids the illumination aside from that due to special shades or reflectors on the lamp itself. Such reflectors are necessary if the light ordinarily thrown above the horizontal plane is to be utilized.

In calculating the illumination due to any type of lamp at a given point it is necessary to know the distribution curve of the lamp used and the distance to the point illuminated. The approximate illumination is given by the formula,

$$I = \frac{c.p.}{h^2 + d^2}$$

when I = illumination in candle-feet.

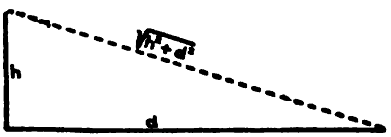


Fig. 40.

c.p. = candle-power of the unit, determined from the distribution curve of the lamp.

h = distance the lamp is mounted above the ground, in feet, and *d* = distance from the base of the pole supporting the lamp to the point where the illumination is being considered. See Fig. 40.

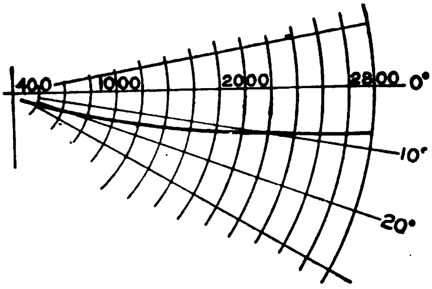


Fig. 41.

While this will give the illumination in candle-feet, the nature of the lighting cannot be decided from this alone, but the total amount of light must also be considered. Thus, a street lighted with powerful units and giving a minimum illumination of .05 candle-foot would be considered better illuminated than one having smaller units so distributed as to give the same minimum value.

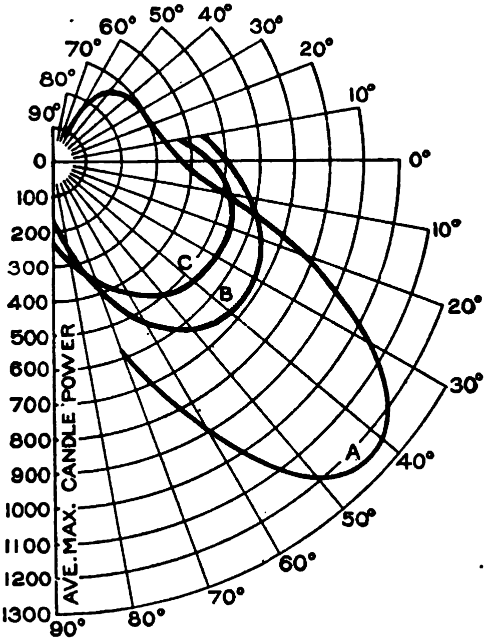


Fig. 42.

Since a uniform distribution of light is desirable, for economic reasons, the ideal distribution curve of a lamp for street lighting would be a curve which shows a low value of candle-power thrown directly downward, but with the candle-power increasing as we approach the horizontal. Such an ideal distribution curve is shown in Fig. 41.

Actual distribution curves taken from commercial arc lamps are given in Fig. 42, in which

Curve A shows distribution curve for a 9.6-ampere, open, direct-current arc.

Curve B shows distribution curve for a 6.6 ampere, D.C. enclosed arc.

Curve C shows distribution curve for a 7.5-ampere, A.C. enclosed arc.
Globes used with B and C are opal, inner globes, clear, outer globes.
Globes used with A are clear outer globes.
A street reflector was used with the enclosed arcs.

A series of curves known as illumination curves may be readily calculated showing the illumination in candle-feet at given distance from the foot of the pole supporting the lamp. Illumination curves corresponding to the distribution curves in Fig. 42 are given in Fig. 43 where A′, B′, and C′ correspond to A, B, and

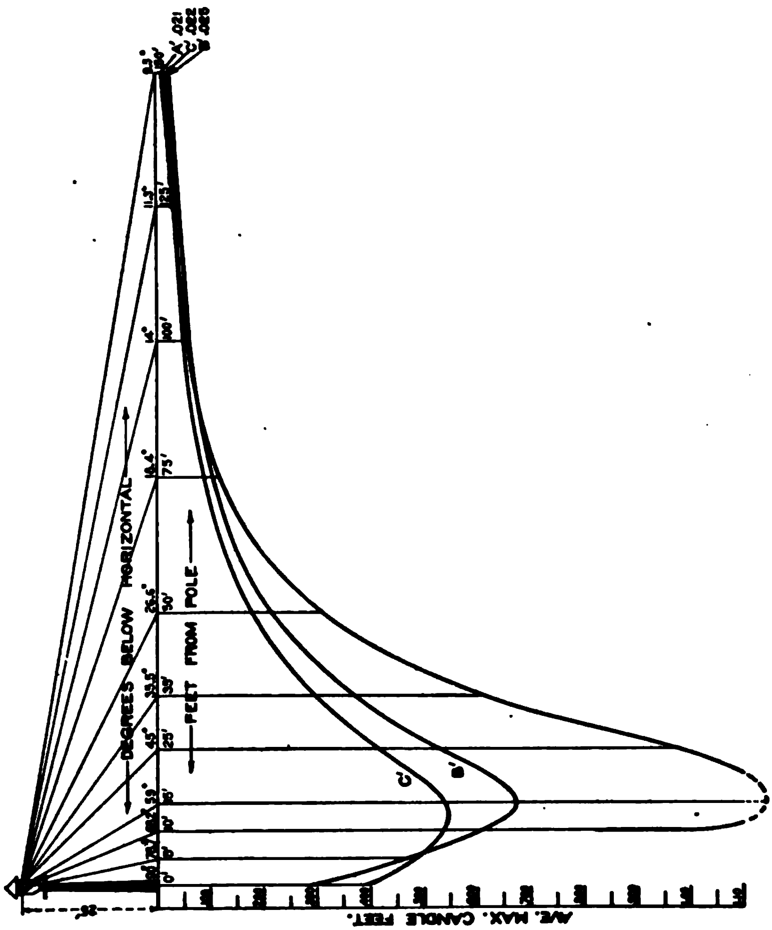


Fig. 43.

C in Fig. 42. These curves correspond to actual readings taken with commercial lamps. Similar curves for incandescent lamps are shown in Fig. 44. A value of .03 candle-foot is about the minimum for good street lighting. Open arcs should be placed at least 25 feet above the ground; 30 to 40 feet is better, especially if the space to be illuminated is quite open. With enclosed arcs it is often advantageous to place them as low as 18 to 20 feet from the ground. Table 9 gives the distance between lights for different types of arcs for good illumination.

TABLE 9.

Kind of Light.	Distance between Lights.	Lights Per Mile.
6.6-ampere enclosed D.C. arc............	340 Feet.	15
9.6-ampere open D.C. arc................	315 "	17
6.6-ampere enclosed A.C. arc............	275 "	19
6.6-ampere open D.C. arc................	260 "	20

In considering the type of arc light to be used we must turn to the illumination curves as shown in Fig. 43. These curves show that the illumination from a direct-current open arc in its present form is superior to that from a direct-current enclosed arc, taking the same amount of power, in the vicinity of the pole, but at a distance of 100 feet, the illumination from the enclosed arc is better. This illumination is still more effective on account of the absence of such strong light as is given by the open arc near the pole. The pupil of the eye adjusts itself to correspond to the brightest light in the field of vision, and we are unable to see as well in the dimly-lighted section as when the maximum intensity is less. The characteristics of the open, direct-current arc lamps are as follows:

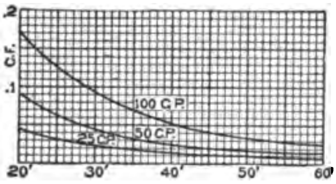


Fig. 44.

The mean spherical candle-power and energy required at the arc are variable.

Fluctuations of light are marked, due to wandering of the arc, flickering due to the wind and lack of uniformity of the carbons.

Dense shadows are cast by the side rods and the lower carbon, while the light is objectionably strong in the vicinity of the pole.

With the enclosed arc the mean spherical candle-power and the watts consumed at the arc are fairly constant.

No shadows are cast by the lamps, and the illumination is not subject to such wide variations. The enclosed arc is much superior to the open arc using the same amount of energy. This applies to the open arc as it is now used. With proper reflection and diffusion of the light such as might be accomplished by extensive or special shading, we ought to be able to get as good distribution from the open arc with a greater total amount of illumination.

In comparing the direct-current with the alternating-current enclosed arc, we see that the direct-current arc gives slightly more light than the alternating lamp, but this may be more than counterbalanced by the better distribution of light from the alternating-current lamp. The selection of A.C. or D.C. enclosed lamps will usually depend on other conditions, such as method of distribution of power, efficiency of plant, etc.

Series incandescent lamps are used considerably for lighting the streets in residence sections of cities or where shade trees make it impracticable to use arcs. These vary in candle-power from 16 to 50 or even higher, and are usually constructed so as to take from two to four amperes. The best arrangement of these is to mount them on brackets a few feet from the curb, with alternate lamps on opposite sides of the street. The distance between the lamps depends on their power. 50 candle-power lamps spaced 100 feet between lamps, give a minimum illumination of .02 candle-foot. 25 candle-power lamps spaced 75 feet between lamps will serve where economy is necessary.

SHADES AND REFLECTORS.

Lamps, as ordinarily constructed, do not always give a suitable distribution of light, while the intrinsic brightness is often too high for interior lighting. Shades are intended to modify the intensity of the light, while reflectors are used for the purpose of changing its direction. Frequently the two are combined in various ways. Shades are also used for decorative purposes, but, if possible, these should be of such a nature as to aid illumination rather than to reduce its efficiency.

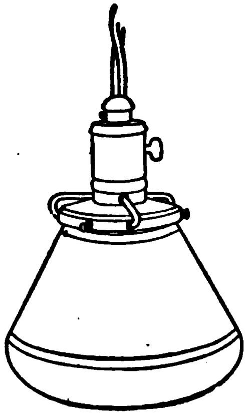


Fig. 45.

A considerable amount of light is absorbed by the material used for the construction of shades. Table 10 shows the approximate amount absorbed by some materials.

Of the great number of styles of shades and reflectors in use, only a few of the more important will be considered here.

TABLE 10.

	Per Cent
Clear glass	10
Alabaster glass	15
Opaline glass	20-40
Ground glass	25-30
Opal glass	25-60
Milky glass	30-60
Ground glass	24.4
Prismatic glass	20.7
Opal glass	32.2
Opaline glass	23.0

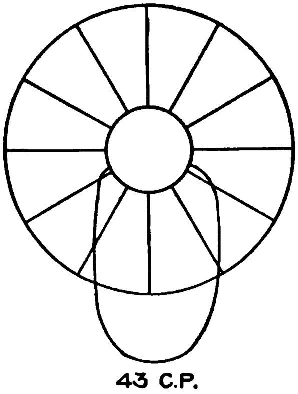


Fig. 46.

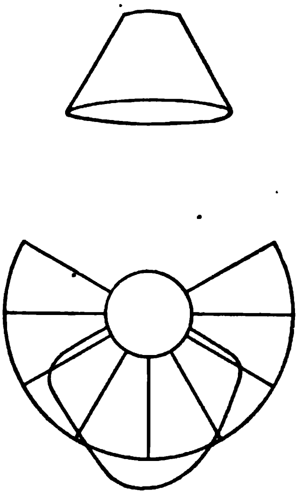


Fig. 47.

One of the simplest methods of shading incandescent lamps is by the use of "frosted" globes. These serve to reduce the intrinsic brightness of the lamp, and should be freely used for residence lighting when separate shades are not installed. Frosted globes are also used in connection with reflectors for the purpose of diffusing the reflected light. The McCreary shade as shown in

Fig. 45 is an example of such a combined shade and reflector. Fig. 46 shows the distribution curve taken from an incandescent lamp using a McCreary shade. Fig. 47 shows the distribution of light from a conical shade. Fig. 39 shows the distribution of light brought about by means of a spiral filament and a reflector as used in the Meridian lamp.

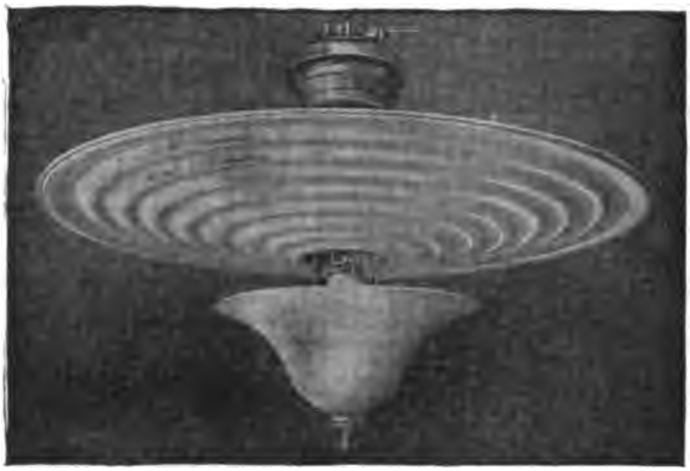


Fig. 48.

Holophane globes are made for both reflecting and diffusing the light, and they can be made to bring about almost any desired distribution with but a small amount of absorption of light. These consist of shades of clear glass having horizontal grooves forming surfaces which change the direction of light by refraction or total reflection as is necessary. The diffusion of light is effected by means of deep, rounded, vertical grooves on the interior surface of the globe. While these globes are of clear glass and absorb an amount of light corresponding to clear glass, the light is so well diffused that the filament of the lamp cannot be seen, and the globe appears as if made of some semi-transparent material. The objections to globes of this type are their high cost and the difficulty in keeping them clean.

Fig. 48 shows an enclosed arc lamp fitted with a concentric "diffuser." This shade is sometimes applied to an inverted arc, which is a direct-current arc in which the lower carbon is made positive. The effect of this combination is best shown in Fig. 49. Fig. 50 shows the change in the illumination curve produced by such shading. Inverted arcs have a considerable application when the light may be readily reflected and diffused as in lighting large rooms with light finish.

Fig. 51 shows another form of adjustable diffuser which finds application when a soft light is required for a definite direction. This shade is very readily adapted to shop lighting.

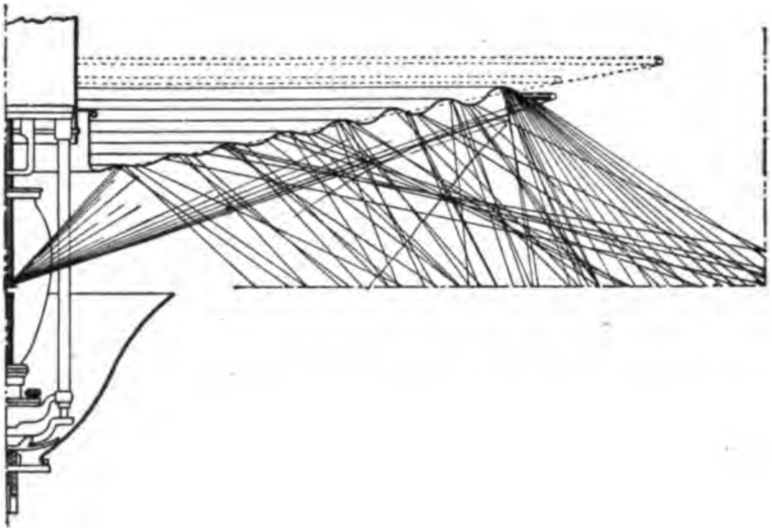


Fig. 49.

The use of opal enclosing globes is recommended for arc lamps used for street lighting for the reason that they change the distribution of the light so that it covers a greater area, and the light is so diffused as to obliterate shadows in the vicinity of the lamp. Table 11 gives the efficiency of different globe combinations for street lighting assuming the opal inner and the clear outer globes as 100%.

TABLE 11.

Opal enclosing and clear outer	100 per cent.
Clear " " clear "	91.2 "
" " " opal "	85.1 "
Opal " " opal "	82.7 "

PHOTOMETRY.

Photometry is the art of comparing the illuminating properties of light sources, and forms one branch of scientific measurement. Its use in electric illumination is to determine the relative values of different types of lamps as sources of illumination, together with their efficiency; also by means of the principles of photometry, we are able to study the distribution of illumination for any given arrangement of light sources.

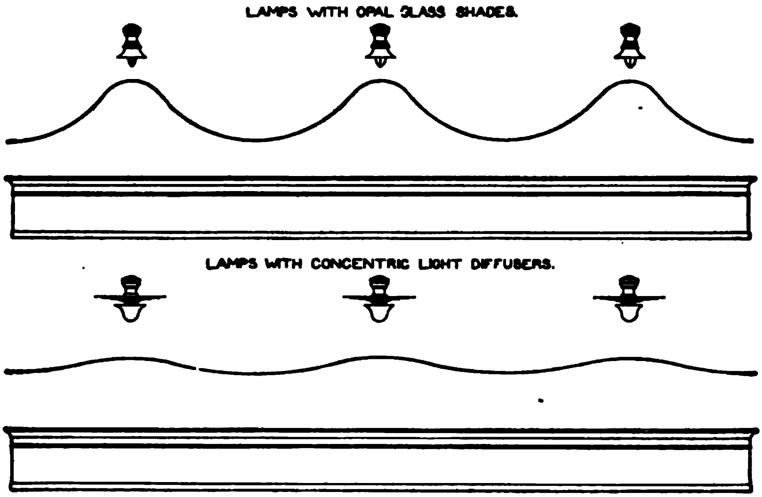

LAMPS WITH OPAL GLASS SHADES.
LAMPS WITH CONCENTRIC LIGHT DIFFUSERS.

Fig. 50.

Light Standards. Inasmuch as sources of light are compared with one another in photometry, we must have some standard, or unit, to which all light sources are reduced. This unit is usually the candle-power and the rating of most lamps is given in candle-power.

While the candle-power remains the unit and is based on the standard English candle, other light standards have been introduced and are much more desirable.

The English Candle. The English candle is made of spermaceti extracted from crude sperm oil, with the addition of a small quantity of beeswax to reduce the brittleness. Its length is ten inches, and its diameter .9 inch at the bottom and .8 inch at the top, and its weight is one-sixth of a pound. Great care is taken in the preparation of the wick and spermaceti. This candle burns with a normal height of flame of 45 millimeters and consumes 120 grains per hour when burning in dry air at normal atmospheric pressure. Under these conditions, the light given by a single candle is one candle-power.

When used for measurements, the candle should be allowed to burn at least fifteen minutes before taking any readings. At the end of this period the wick should be trimmed, if necessary, and when the flame height reaches 45 millimeters, readings can be taken. The candle should not require trimming when the proper height of flame has been reached. It is best to weigh the amount of material consumed by balancing the candle on a properly arranged balance when the first reading is taken, and again balancing at the end of a suitable period—ten to fifteen minutes. The candle-power of the unit is then, practically, directly proportional to the amount of the material consumed.

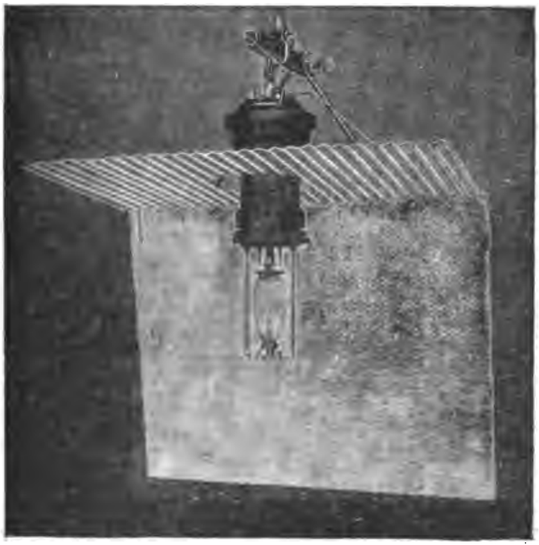


Fig. 51.

The objections to the candle as a unit are that it burns with an open flame which is subject to variation in height and to the effect of air currents. The color of the light is not satisfactory, being too rich in the red rays and the composition of the spermaceti is more or less uncertain.

The German Candle is made of paraffine, very pure, and burns with a normal flame height of 50 millimeters and is subject to the same disadvantages as the English candle. It may be necessary to trim the wick to keep the flame height at 50 millimeters. The light given is a trifle greater than for the spermaceti candle.

The Carcel Lamp is built according to very careful specifications and burns colza (rape seed) oil. It has been used to a large extent in France, but its present application is limited.

The Pentane Lamp is a specially constructed lamp burning pentane, prepared by the distillation of gasoline between narrow limits of temperature. This standard is not extensively used.

The Amyl Acetate Lamp. This lamp, known also as the Hefner lamp, is at present the most desirable standard. It is a lamp built to very careful specifications, especially with regard to the dimension of the wick tube. It burns pure amyl acetate and the flame height should be 40 millimeters. This flame height must be very carefully adjusted by means of gauges furnished with the lamp. Amyl acetate is a colorless hydrocarbon prepared from the distillation of amyl alcohol obtained from fusil oil, with a mixture of acetic and sulphuric acids, or by distillation of a mixture of amyl acetate, sulphuric acid, and potassium acetate. It has a definite composition, and must be pure for this use.

The most serious disadvantage of this standard is the color of the light, inasmuch as it has a decidedly red tinge and is not readily compared with whiter lights. Its value is affected somewhat by the moisture in the air and the atmospheric pressure, but it excels all other standards in that it is quite readily reproduced.

Below is given the accepted value of the English and German candle in terms of the Hefner unit.

The Paraffine Candle (Vereinskerze) at a flame height of 50 millimeters. } = 1.2 Hefner Units.

The English candle at a flame height of 45 millimeters.... } = 1.14 Hefner Units.

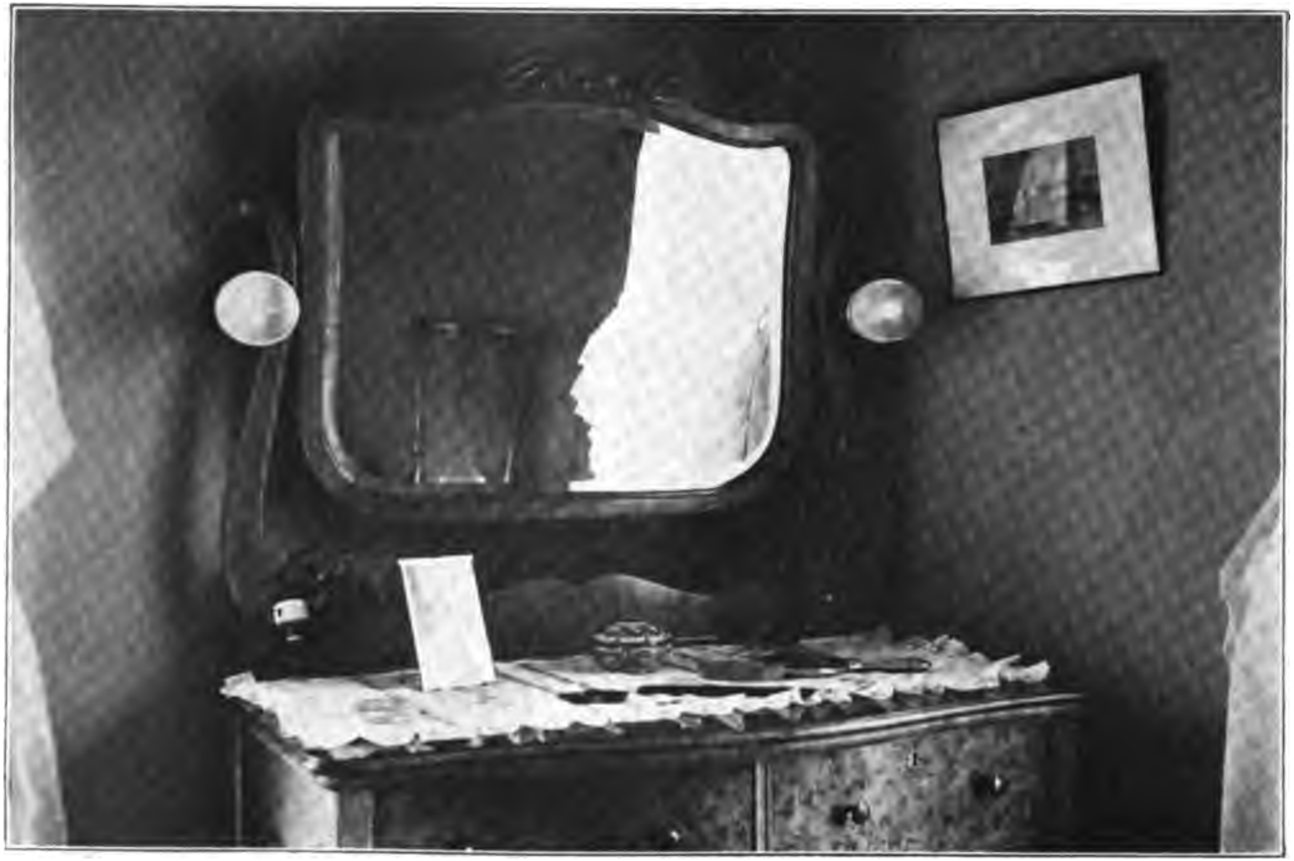
Working Standards. The units just described, together with some others, form reference standards, but an incandescent lamp is generally used as the working standard in all photometers. An incandescent lamp, when used for this work, should be burned for about two hundred hours, or until it has reached the point in the life curve where its value is constant, and it should then be checked by means of some standard when in a given position and at a fixed voltage. It then serves as an admirable working standard if the applied voltage is carefully regulated. Two such lamps should always be used—the one to serve as a check on the other; the checking lamp to be used for very short intervals only.

Photometers. Two light sources are compared by means of a photometer which, in one of its simplest forms, consists of what is known as a Bunsen screen mounted on a carriage between the two lights being compared, with its plane at right angles to a line passing through the light sources, and arranged with mirrors or prisms so that both sides of the screen may be observed at once. The Bunsen screen consists of a disc of paper with a portion of either the center, or a section around the center, treated with paraffine so as to render it translucent. If the light falling on one side of this screen is in excess, the translucent spot will appear dark on that side of the screen and light on the opposite side. Care must be taken to see that the two sides of the screen are exactly alike, otherwise there will be an error introduced in using the screens. It is well to reverse the screen and check readings whenever a new lot of lamps are to be tested. When the light falling on the two sides of the screen is the same, the transparent spot disappears. The values of the two light sources are then directly proportional to the square of their distances from the screen. As an example, consider a 16 candle-power lamp being compared with a standard candle. Say the translucent spot disappears when the screen is distant 60 centimeters from the standard candle, we then have the proportion,

$$x : 1 = (240)^2 : (60)^2 = 16 : 1,$$

showing that the lamp gives 16 candle-power.

The above law is known as the law of inverse squares, and holds true only when the dimensions of the light sources are small compared with the distance between them, and when there are no reflecting surfaces present as when the readings are taken in a dark room.



GOOD METHOD OF LIGHTING UP A DRESSER.

The proof that the light varies inversely with the square of distance from the source is as follows:

Consider two spherical surfaces, Fig. 52, illuminated by a source of light at the center. The same quantity of light falls on both surfaces.

$$\text{Area of } S = 4\pi R^2 \text{ sq. ft. (R is in feet.)}$$

$$\text{Area of } S_1 = 4\pi R^2_1 \text{ sq. ft.}$$

Let Q = total quantity of light and q = light falling on unit surface. Then,

$$q = \frac{Q}{4\pi R^2}$$

$$q_1 = \frac{Q}{4\pi R^2_1}$$

$$q : q_1 = \frac{Q}{4\pi R^2} : \frac{Q}{4\pi R^2_1}$$

$$= 4\pi R^2_1 : 4\pi R^2$$

$$\frac{q}{q_1} = \frac{R^2_1}{R^2}$$

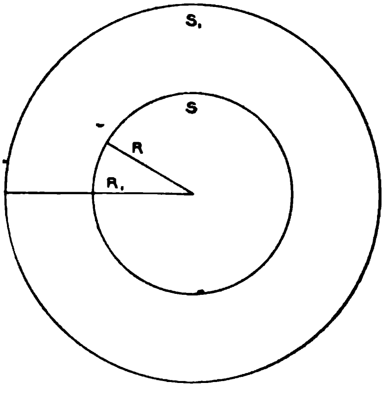


Fig. 52.

Fig. 53 shows the relation in another way. The area of C, distant two units from the source of light A, is four times that of B which is distant one unit.

The Lummer-Brodhun Photometer. In addition to the Bunsen Screen described, there are several other forms of photometers, the most important of which is the Lummer-Brodhun. The essential feature of this instrument is the optical train which serves to bring into contrast the portions of the screen illuminated by the two sources of light. Referring to Fig. 54, the screen S is an opaque

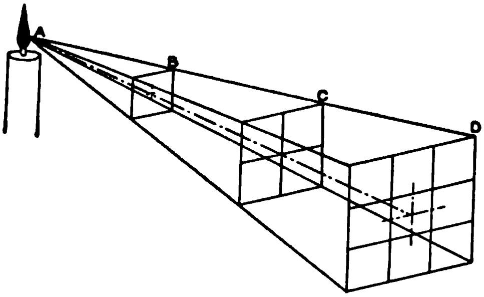


Fig. 53.

screen which reflects the light falling upon it from L, to the mirror M, when it is again reflected to the pair of glass prisms A, B. The surfaces *sr* are ground to fit perfectly and any light falling on this surface will pass through the prisms. Light falling on the surface *ar* or *bs* will be reflected as shown by the arrows. We see then that the light from L, which falls on *ar* and *bs*, is reflected to the eye piece or telescope T, while that falling on *sr* is transmitted to and absorbed by the black interior of the containing box. Likewise, the light from the screen L_1 is reflected by the screen M_1 to the pair of prisms A, B. The rays falling on the surface *sr* pass through to the telescope T, while the rays falling on *ar* and *bs* are reflected and absorbed by the black lining of the case. The field of light, as then viewed through the telescope, appears as a disc of light produced by the screen L_1, surrounded by an annular ring of light produced by L. When the illumination on the two sides of the screen is the same, the disc and ring appear alike and the dividing circle disappears.

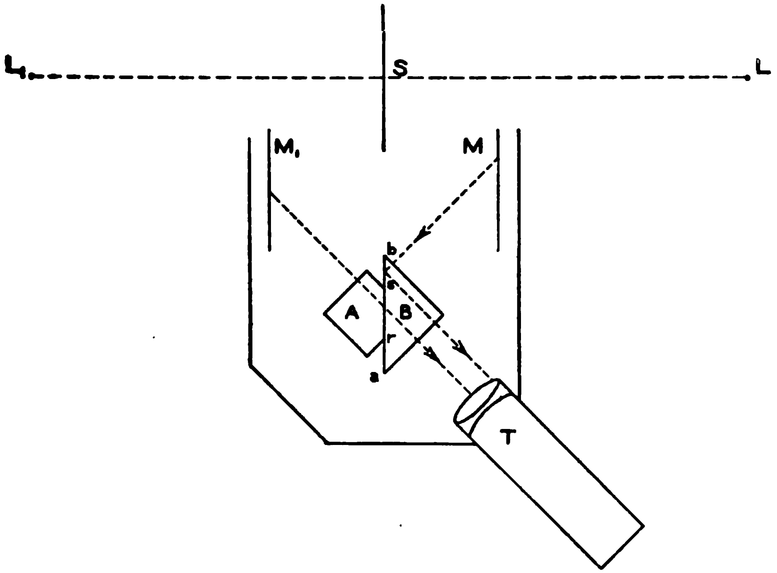


Fig. 54.

In using this screen, it is mounted the same as the Bunsen screen and readings are taken in the same manner. The screen and prisms are arranged so that they can be reversed readily and two readings should always be taken to compensate for any inequalities in the sides of the screen and the reflecting surfaces, a mean of the two readings serving as the true reading. This form of screen is used when especially accurate comparisons are required.

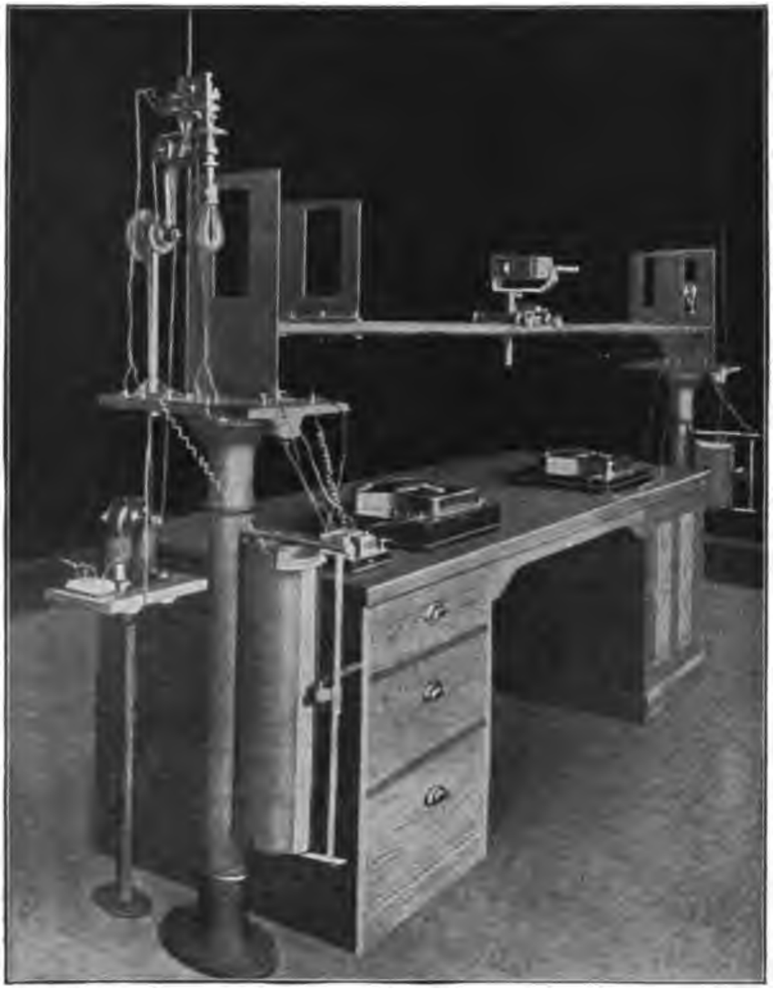


Fig. 55.

Fig. 55 shows a complete photometer with a Lummer-Brodhun screen, while Fig. 56 shows a Bunsen Screen and sight box.

In Fig. 55, the lamps are shaded by means of curtains so as to leave only a small opening toward the screen.

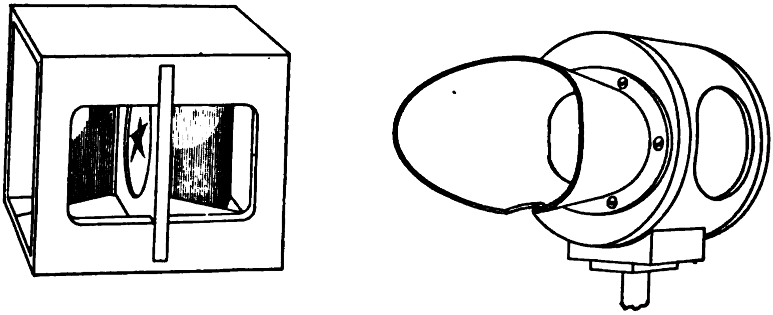


Fig. 56.

The Weber Photometer. As an example of a portable type of photometer, we have the Weber. This photometer, shown in Fig. 57, is very compact and is especially adapted to measuring intensity of illumination as well as the value of light sources; it may be used for exploring the illumination of rooms or the lighting of streets.

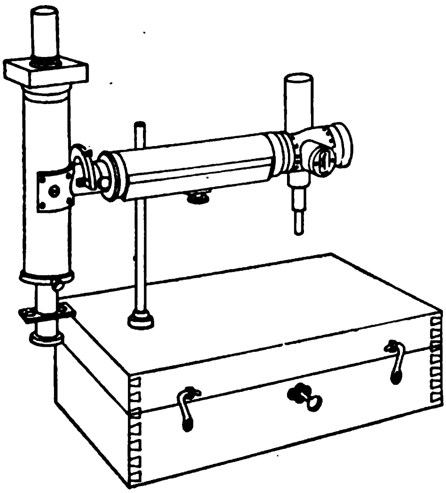


Fig. 57.

This apparatus consists of a tube A, Fig. 58, which is mounted horizontally and contains a circular, opal glass plate *f*, which is movable by means of a rack and pinion. To this screen is attached an index finger which moves over a scale attached to the outside of the tube. A lamp L, burning benzine, is mounted at the end of this tube. The benzine used should be as pure as possible, and the flame height should be carefully adjusted to 20 mm. when taking readings. At right angles to the tube A is mounted the tube B which contains an eye piece at O, a Lummer-Brodhun contrast prism at *p* and a support for opal or colored glass plates at *g*.

Operation. The tube B is turned toward the source of light to be measured, the distance from the light to the screen at *g* being noted. The light from this source is diffused by the screen at *g*, while that from the standard is diffused by the screen *f*. By moving the screen *f*, the light falling on either side of the prism *p* can be equalized. The value of the unknown source can be determined from the reading of the screen *f*, the photometer having previously been calibrated by means of a standard lamp in place of the one to be measured. The calibration may be plotted in the form of a curve or it may be denoted by a constant, C, when we have the formula,

$$I' = C\frac{L^2}{l^2}$$

C corresponds to a particular plate at *g*,

l = distance of screen *f* from the benzine lamp, and L = distance from the screen *g* to the light source being measured. Screens of different densities may be used at *g*, depending on the strength of the light source.

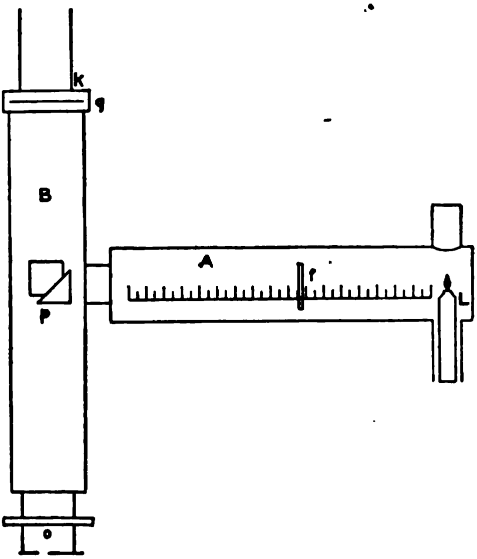


Fig. 58.

When used for measuring illumination, a white screen is used in connection with this photometer. The screen is mounted in front of the opening at *g*, and turned so that it is illuminated by the source being considered. Readings of the screen *f* are taken as before. A calibration curve is plotted for the instrument, using a known light source at known distance from the white screen when the instrument is mounted in a dark room.

A photometer, known as the **Matthews' Integrating Photometer**, has recently been placed on the market, and a very good idea

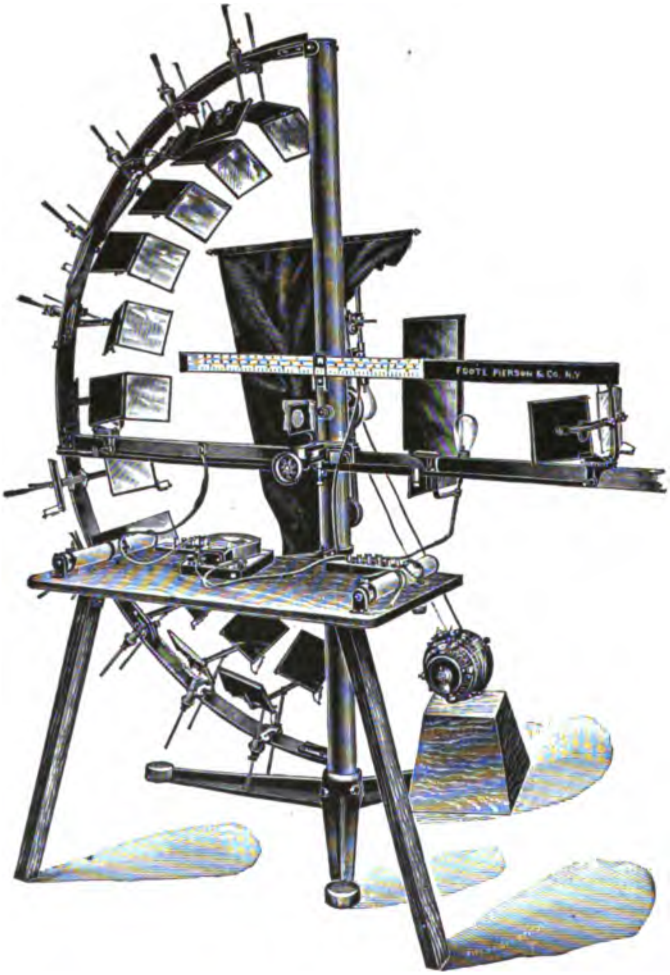

FOOTE, PIERSON & CO. N.Y.

Fig. 59.

of its construction can be obtained from Fig. 59. By means of a system of mirrors, the light given by the lamp in several directions may be integrated and thrown on the photometer screen for comparison with the standard, the result giving the mean spherical candle-power from one reading. By covering all but one pair of screens, the light given in any one direction is easily determined.

Incandescent Lamp Photometry. *Apparatus.* Some sort of screen, either the Bunsen type or the Lummer-Brodhun screen preferred, should be mounted on a carriage moving on a suitable scale, and the lamp holders, one for the standard, the other for the lamp to be tested, are mounted at the ends of this scale. There are several types of so-called station photometers arranged so as to be very convenient for testing incandescent lamps. Fig. 60 shows one form of station photometer manufactured by Queen & Co. The controlling rheostats and shielding curtains are not shown here. Fig. 61 shows a form of portable photometer for incandescent lamps. The length of scale should not be less than 100 centimeters, and 150 to 200 centimeters is preferred. This scale may be divided into centimeters or, for the purpose of doing away with much of the calculation, the scale may be a *proportional scale.* This scale is based on the law of inverse squares and reads the ratio of the squares of the distances from the two lights being compared. If the standard used always has the same value, the scale may be made to read in candle-powers directly.

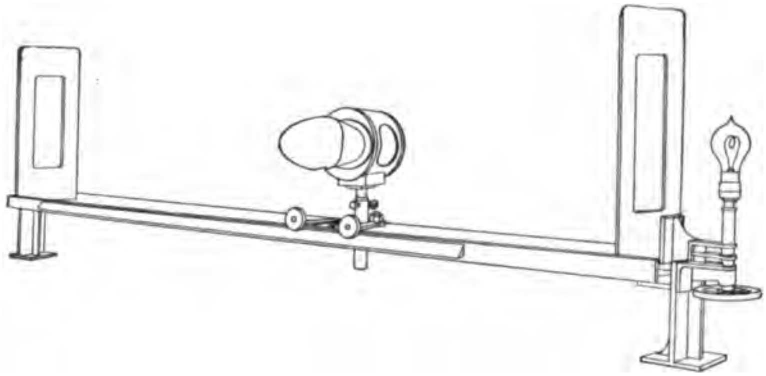


Fig. 60.

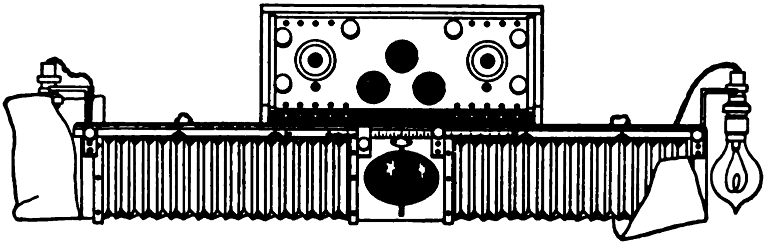


Fig. 61.

For mean horizontal candle-power measurements, the lamp should be rotated at 180 revolutions per minute, when mounted in a vertical position.

For distribution curves a universal lamp holder which will allow the lamp to be placed in any position, and which indicates this position, is used.

For mean spherical candle-power, the following method is used when the Matthews photometer is not available:

The lamp is placed in an adjustable holder and readings taken with the lamp in thirty-eight positions, as follows:

The measurement of the spherical intensity. For convenience the tip of the lamp and its base may be termed the north and south poles respectively.

“The mean of 13 readings taken at intervals of 30°, is taken to give the mean horizontal candle-power.

Beginning again at 0° azimuth, thirteen readings are made in the prime meridian or vertical circle, the interval again being 30°, and the last reading checking the first.

It will be noticed that four readings, two being check readings, have been made at 0° azimuth in each case. The mean of the four is taken as the *standard reading*, it being the value of the intensity, in this position, should the lamp be used as a standard.

Additional sets of thirteen readings each—the last reading checking the first one—are similarly made on each of the vertical circles through 45°, 90°, and 135° azimuth.

In combining the readings for the mean spherical intensity, a note is taken of the repetitions.

Neglecting the repetitions, which may also be omitted in part, in the practice of the method, there remain thirty-eight points, as follows:

	Distributed Values.
The mean of four measurements at the north pole of the lamp......	1
Four measurements on each of the vertical circles through 0° and 90° azimuth at vertical circle readings of 60°, 120°, 240°, and 300°.	8
Four measurements on each of the vertical circles through 0°, 45°, 90°, and 135° azimuth at vertical circle readings of 30°, 150°, 210°, and 330°..	16
Twelve measurements 30° apart at the equator....................	12
Four null values at the south pole of lamp.........................	1
Total number of effective measurements..........................	38

The points thus laid off on the reference sphere are approximately equidistant, being somewhat closer together at the equator than at the poles."

When the lamp is rotated, readings are taken for each 15° or 30° in inclination, from 0° to 90°, and from 0° to 270°. These are integrated values for their corresponding parallels of latitude on the unit sphere.

The mean spherical candle-power from these readings may best be obtained by plotting a distribution curve from the readings, determining the area of this closed curve by means of a planimeter and taking the radius of an equivalent circle as the value for the mean spherical candle-power.

In all tests the voltage of the lamp must be very closely regulated. A storage battery forms the ideal source of current for such purposes. In testing incandescent lamps a standard similar to the lamp being tested is desirable and it should, preferably, be connected to the same leads. Any variation in the voltage of the mains then affects both lamps and the error introduced is slight.

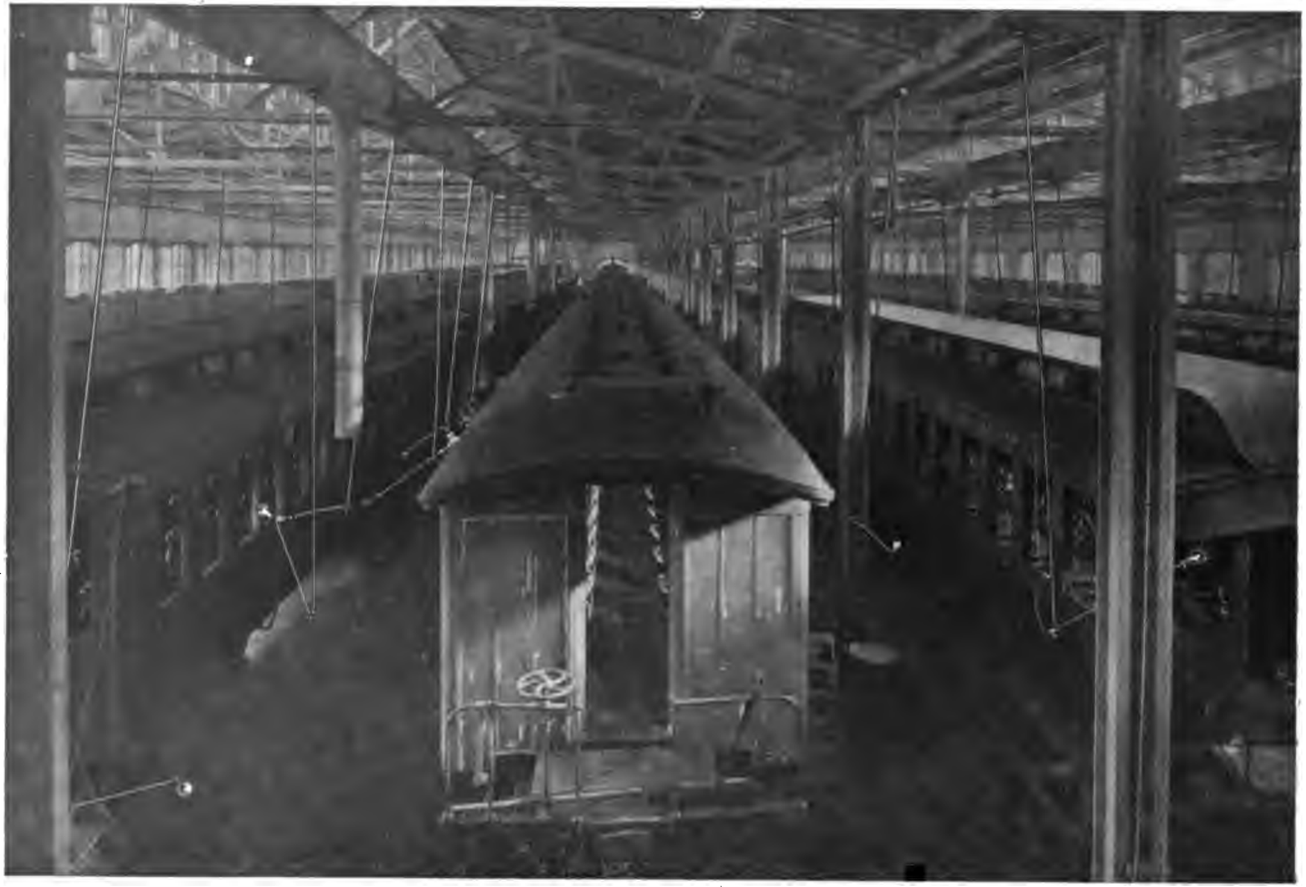
Arc Light Photometry. Owing to the variation of the amount of light given out by an arc lamp in one direction at any time, due to variation of the qualities of the carbons, position of the arc, and also on account of the color of the light, etc., the photometry of arc lamps is much more difficult than that of incandescent lamps. The curves shown in Figs. 10 and 11 are average distribution curves taken from several lamps and will vary considerably for any one lamp. If the arc is enclosed, this variation is not so great.

The working standard should be an incandescent lamp run at a voltage above the normal so that the quality of the light will compare favorably with that of the arc. Since an incandescent lamp deteriorates rapidly when run at over voltage, the standard can be used only for short intervals and must be frequently checked.

Since an arc lamp can be mounted in one position only, mirrors must be used to obtain distribution curves. A mirror is used mounted at 45° with the axis of the photometer, and arranged so as to reflect the arc when in different positions. A mirror absorbs a certain per cent of the light falling upon it and this percentage must be determined by using lamps previously standardized. The length of the photometer bar must include the distance from the mirror to the arc.

The Weber photometer is well adapted to arc-light measurements inasmuch as appropriate screens may be used to cut down the intensity of the light.

A special form of the Matthews' photometer is also used for testing arc lamps.



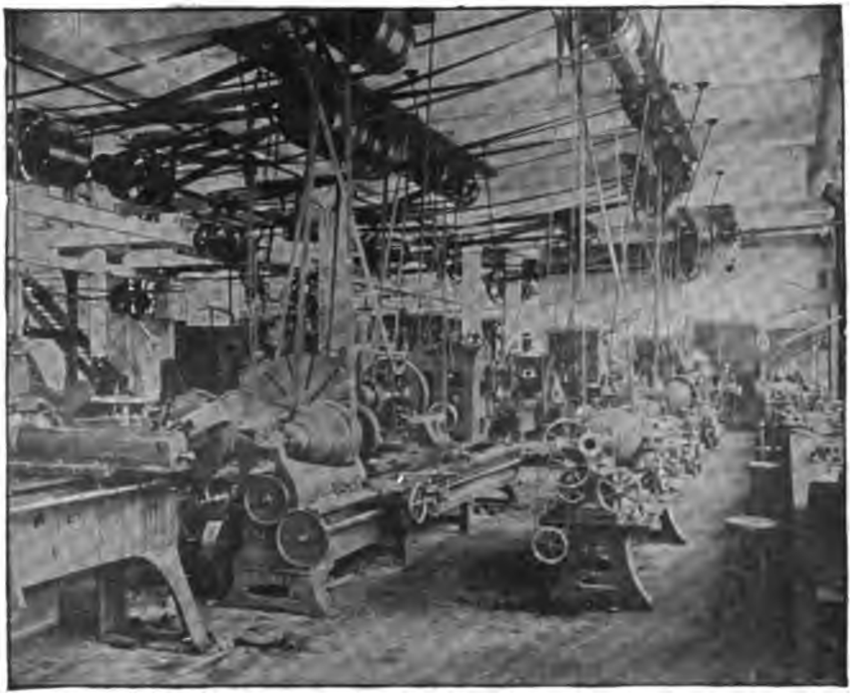
INTERIOR OF PAINT SHOP, BOSTON AND ALBANY R.R., ALLSTON, MASS.

Incandescent Lights Installed with White Adjustable Fixtures.

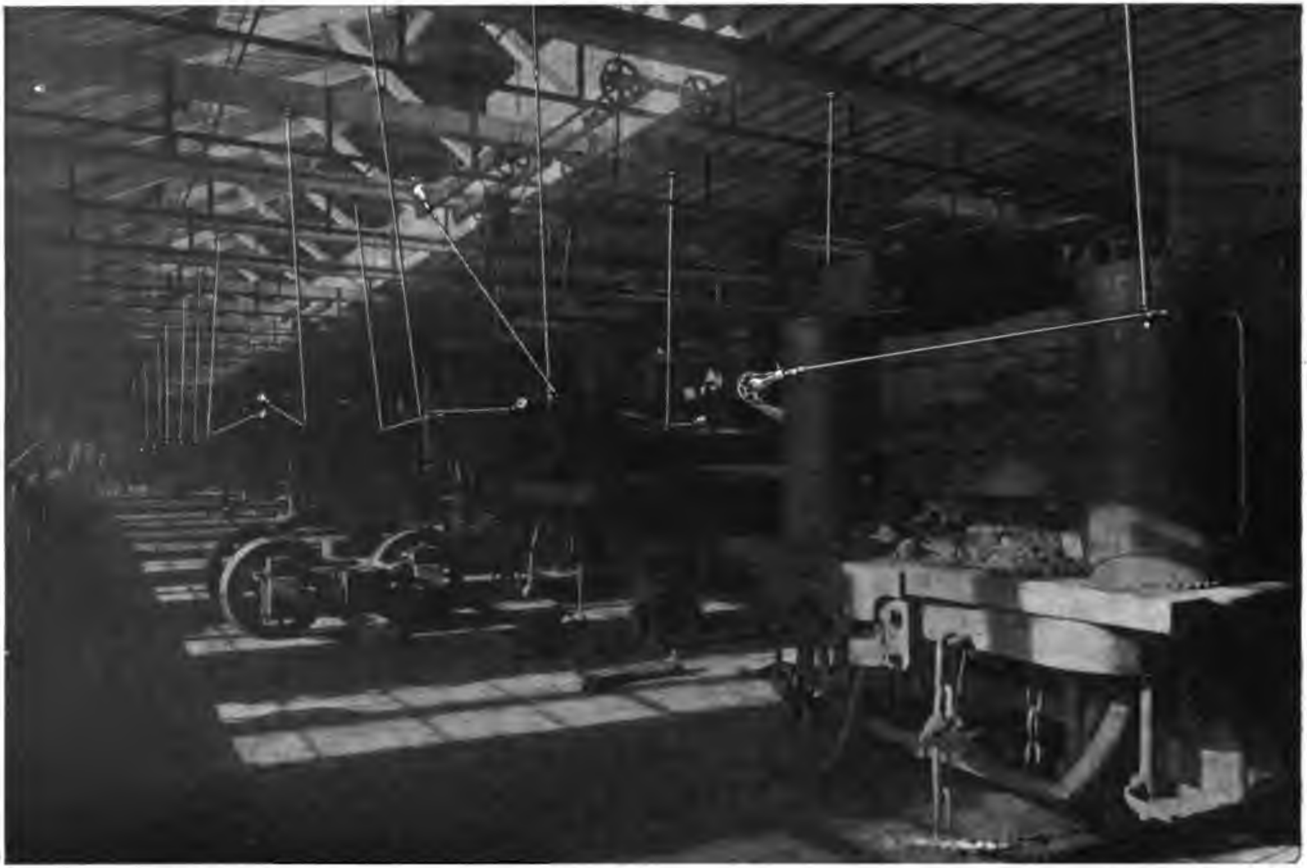
O. C. White Company.

SHOP LIGHTING.

It is only within a few years that what is now regarded as proper attention to lighting has been considered in the design and construction of factory buildings. Formerly, a shop seemed to be designed more to protect the tools and materials from the weather, than to afford any degree of convenience or comfort for the workmen. It is now regarded as good business policy (in other words, it pays) to provide buildings which are properly heated, lighted, and ventilated. In such buildings, it has been found that workmen are more content, do better work, and produce more. From the old-fashioned blacksmith shop, in which each smith was supposed to work by the light of his own fire, it is a far cry to shops such as those of the National Cash Register Company at Dayton,



BOSTON & ALBANY RAILROAD MACHINE SHOP, WEST SPRINGFIELD, MASS.
Equipped with White Adjustable Fixtures.



INTERIOR OF REPAIR SHOP, BOSTON AND ALBANY R.R., ALLSTON, MASS.

Incandescent Lights with White Adjustable Fixtures.

O. C. White Company.

Ohio, in which the comfort and convenience of the employees has been given a degree of attention that seems to the old shop managers to partake of the nature of coddling.

DISTRIBUTION OF SUNLIGHT.

In considering this question of lighting, it is well understood that daylight is the best light, especially when it is not accompanied by the direct rays of the sun. To properly distribute daylight—which is, of course, the cheapest light—over large areas, is the first problem to be considered in the design of new shop buildings. This may be accomplished in a number of ways. Where buildings are several stories in height, and where light, except in the upper story, must be admitted from side windows, those windows should reach from the top of the bench to the ceiling. A given amount of glass arranged in this manner gives a much better general distribution of light than the same amount of glass put into the ordinary form of short windows. The amount of light in the center of the room depends very largely upon the height of the windows at the side. All modern factory buildings

WHITE ADJUSTABLE FIXTURES IN WORCESTER SAFE DEPOSIT & TRUST COMPANY, WORCESTER, MASS.

are now lighted by long, narrow windows. The common type of shop, consisting of an open floor with a gallery on both sides, is usually lighted, in addition to the tall side windows, by glass in the sides of the monitor roof. If these monitor windows are kept clean, they add greatly to the light of the main floor.

The best system of roof lighting is by means of what is termed a "saw-tooth" roof, the short and comparatively steep side of the tooth being composed wholly of glass. This glass should face as nearly north as possible, in order to avoid the direct sunlight. In this connection, it will be remembered how the workmen of the old school, especially if employed on work requiring close application, always selected a north window, even if the view therefrom was not so pleasing as that from some other point of the compass. This saw-tooth roof may be used on the top of a monitor in place of side windows, and it results in a much better lighted floor.

WELSBACH BURNER,
With silvered glass reflector.

Old shops, in which a change in amount or location of glass area is impossible, can have their light increased in amount and better distributed by a judicious arrangement of machines, and, particularly, by keeping the walls and ceilings as nearly pure white as possible. Whitewash is so cheap and so easily applied by modern pneumatic methods, that there is little or no excuse for neglect in this particular. Whitewash can easily be made so that it will not readily rub off, in fact, so that it can be washed; but in most cases a fresh application is preferable to cleaning The removal of all possible belting (which can be accomplished by electric driving, either individually or by the group system) adds largely to the lighting effect, and also, by the suppression of dust and flying oil, keeps the walls and ceilings in much better condition. Some factories carry this whitening effect to the point of having the machine tools painted white and varnished. This not only avoids dark spots in the room, but shows plainly any neglect of machinery. In a shop equipped in this manner, the dirty and slothful workman is entirely out of place, and he usually changes his habits or seeks some other shop where his natural conditions prevail.

ARTIFICIAL LIGHTING.

Artificial lighting, which is usually required in northern latitudes, may be divided into three classes: General lighting, individual lights, and portable lights.

Lighting by candles, except in some cases of portable lights, has entirely disappeared; but many country shops still have to depend upon oil as an illuminant. In such cases, large lamps of the Argand type are suspended from the ceiling for general illumination, and small flat-wick lamps, preferably on swinging wall brackets, are used for the individual. The quality of this illumination depends, first, upon the care of the lamps, and, second, upon the quality of the oil. Oil lights at best are dirty and entail a large amount of labor. They are objectionable in that they must be kept from draughts of air, which smoke the chimneys, and thus the shop is often deprived of proper ventilation.

Gas is more frequently used for shop lighting than any other artificial illuminant. It may be classed under the heads of oil gas, coal gas, natural gas, and acetylene. For the isolated shop, oil gas and acetylene are particularly adapted, as such gas plants are easily installed and require but little attention. In every case, the gas plant should be entirely separate from the factory building, and preferably under ground. While acetylene furnishes a light almost ideal in character, it is particularly poisonous, although leakage is readily detected by its odor. A more serious drawback is that this gas forms violently explosive compounds when mixed with air in comparatively small proportions. Many serious and some fatal accidents have occurred by failure to realize the importance of this fact. These installations should be made only by those thoroughly familiar with the subject, and their use must be carefully guarded.

Coal gas is very largely used for shop lighting, on account of its comparative cheapness and the fact that, even in small cities, it can be readily obtained. As it is also used in many shops for heating, in connection with the Bunsen burner and blowpipe, it serves a double function which renders it peculiarly adapted for factory purposes. The ordinary open fish-tail burner, consuming about six cubic feet per hour, is the type of burner generally used. This light is objectionable on account of the fact that it vitiates the air; this, in the winter months when the windows are closed, becomes a serious matter, and calls for largely increased ventilation. The light flickers, even in still air, which makes it very trying to one's eyes when engaged on fine work, and this difficulty is further increased by currents of air caused by open windows or moving belts.

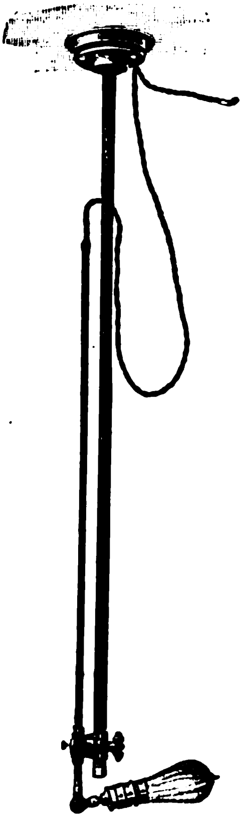
ORDINARY WELSBACH BURNER.

THE WELSBACH BURNER.

Ordinary illuminating gas used in connection with a Welsbach burner, furnishes a very steady light with about one-half the gas consumption necessary for the open light. The Welsbach light is best suited for general lighting, where two or more burners are contained in the same globe and suspended from the ceiling. As an individual light, the Welsbach is not in great favor, on account of its ghastly color combined with a faint tinge of green, which renders it objectionable to many workmen. The mantle used in the Welsbach light is extremely fragile, and it is quickly put out of commission by shocks, vibration, and air currents. For these reasons it is not so well suited for use in the shop as it is for domestic purposes. The Welsbach light, however, is not dependent upon the illuminating quality of the gas, but upon the incandescence of the mantle, which may be produced by any form of fuel gas without the enriching necessary to make it suitable for use in an open burner. Natural gas, therefore, which is used for heating in many sections of the country, can also be used for lighting if employed in the Welsbach burner. As this gas is very cheap, it often pays to use it in this manner.

OPEN—ARC LAMP, DOUBLE. Old Style.

OPEN—ARC LAMP, SINGLE. Old Style.



WHITE ADJUSTABLE CEILING FIXTURE FOR INCANDESCENT LIGHT. Style A.

ELECTRIC LIGHTING.

Electric lighting is rapidly being introduced for shop purposes, especially when the current is generated in the factory. The arc light is commonly used for general illumination, and the incandescent light for the individual. The open arc light is being supplanted by the enclosed arc, with a distinct gain in economy and safety. The open arc, even with the best quality of carbon, is somewhat noisy, and is subject to disagreeable flickering, while the falling of pieces of incandescent carbon, is not only annoying, but dangerous. The enclosed arc light requires less frequent trimming, is more steady, and owing to the fact that it is enclosed, it absolutely prevents danger from falling particles of carbon. Arc lights for general illumination are usually in the vicinity of 1,200 candle-power.

ENCLOSED ARC LAMP.
GLOBE IN TRIMMING POSITION.

WESTINGHOUSE SERIES—ALTERNATING
ENCLOSED—ARC LAMP.

The 16-candle-power incandescent lamp is generally used for individual light; but the 8-candle-power lamp, with a suitable reflector, is less dazzling and furnishes all the light necessary. The

White Adjustable Bench Fixture Incandescent Light. Style D.

system adopted in some drafting rooms, of using an inverted arc—that is, one with the crater in the lower carbon—combined with a reflector to throw the light directly to the ceiling, results in a uniformly diffused light. This avoids the sharp shadows cast by the direct light from the arc, and has much to recommend it as a shop light, especially if the ceilings and walls are kept white.

There are several styles of fixtures used in connection with the incandescent light to place the lamp in any desired position, as the ordinary drop light is very inconvenient in this particular. The White fixture, with its ball-and-socket joint, is one of the best.

In connection with the question of electric lighting, the necessity of maintaining a constant voltage is one that is not given the

COOPER HEWITT LAMP FOR GENERAL INTERIOR LIGHTING.
Type H 7, an improved form of Type V 5. Can be operated in horizontal, vertical or inclined position.

attention it deserves. It is almost impossible to secure satisfactory lighting from a generator driven by the main engine, and this is especially true if electric cranes are also operated from this generator. In the best practice it is considered necessary to have a separate engine and generator to be used solely for the lighting system. A generator driven by the main engine is found satisfactory for crane service.

COOPER HEWITT LAMP FOR INTERIOR LIGHTING WHERE MODERATELY STRONG ILLUMINATION IS DESIRED.

Designed for series installation—two in series on 100 to 120 volts direct current. Suspended at an angle of 20° from ceiling or fastened to wall. Type H 6.

The Cooper Hewitt Light. The Cooper Hewitt mercury vapor lamp is the cheapest form of electric lighting, and will undoubtedly be the commercial light for factory use, especially in shops doing a fine class of work. The color of this light, due to the total absence of red rays, is objectionable but not injurious; and further experiments will undoubtedly produce a light based on this principle which will meet many requirements.

For portable lighting, there is nothing at present superior to the incandescent lamp, for, by means of a long flexible cord, it can be taken to any position. The incandescent lamp, furnished with a magnetic base, can be attached to any iron or steel surface, where it will remain until the light is extinguished. For erection work, particularly, this type of lamp is peculiarly adapted.

INDEX

Part I—ELECTRIC WIRING; *Part II*—ELECTRIC LIGHTING

A

Part Page

- Alternating-current circuits I, 40
  - calculation of I, 44
  - line capacity I, 43
  - mutual induction I, 42
  - skin effect I, 42
- Alternating-current lines, calculation of drop in I, 44
- Amyl acetate lamp II, 61
- Arc-lamp carbons II, 23
- Arc lamps II, 14
  - for alternating currents II, 21
  - carbons II, 23
  - for constant-potential D. C. systems II, 21
  - efficiency of II, 23
  - electric arc II, 14
  - interchangeable II, 22
  - mechanisms of II, 15
    - carbon-feed II, 19
    - differential II, 18
    - series II, 17
    - shunt II, 16
  - rating of II, 22
  - for series systems II, 21
- Arc light photometry II, 71
- Armored cable I, 6
- Artificial lighting II, 77

B

- Batteries I, 92
- Bell push I, 92
- Bremer arc lamp II, 31
- Bushings I, 65

C

- Carbon-feed lamps II, 19
- Concealed knob and tube wiring I, 13
- Conductors, calculation of sizes of I, 25
- Conduit bushing I, 65
- Cooper-Hewitt light II, 82

Part Page

- Crib-bracing, I, 74
- Cross-arms, I, 75
- Cut-out panel, I, 67

D

- Differential lamps, II, 18
- Distribution of light, II, 12
- Double-carbon lamps, II, 19
- Drop in A. C. lines, I, 44

E

- Edison fuse-plug, I, 67
- Efficiency of
  - arc lamps, II, 23
  - incandescent lamps, II, 8
- Electric arc, II, 14
- Electric bell wiring, I, 89-98
  - circuits, I, 95
  - joints, I, 91
  - methods of, I, 90
  - outfit, I, 92
    - batteries, I, 92
    - bell, I, 94
    - bell push, I, 92
  - wire for, I, 89
- Electric lighting, II, 3-72, 79
  - history and development of, II, 3
  - illumination, II, 40
  - photometry, II, 59
  - power distribution, II, 164
  - types of lamps used
    - arc (see "Arc"), II, 14
    - incandescent (see "Incandescent"), II, 4
    - special (see "Special"), II, 23
- Electric wiring, I, 1-87
- Enclosed D. D. arc lamps, II, 21
- English candle, II, 59

F

- Fibre conduit, I, 83
- Fibrous tubing, I, 15
- Flexible metal conduit, I, 4
- Frosted globes, II, 56
- Fuse-boxes, I, 66

G

- Galvanometer, I, 37
- German candle, II, 61
- Glowers, II, 25
- Guy cable, I, 74

H

Part Page

- Hefner unit II, 61
- Holophane globes II, 57

I

- Illumination II, 40
  - definition of II, 40
  - intrinsic brightness II, 40
  - public halls, offices, etc II, 48
  - regular reflection II, 41
  - residence II, 42
  - street II, 51
  - unit of II, 40
- Incandescent lamp photometry II, 68
- Incandescent lamps II, 4
  - distribution of light II, 12
  - efficiency II, 8
  - manufacture of II, 5
    - exhausting II, 7
    - filament II, 5
    - flashing II, 6
  - relation of life to efficiency II, 9
  - selection of II, 10
  - voltage and candle-power II, 8
- Insulators I, 77
  - wires run exposed on I, 16
    - accessibility I, 17
    - cheapness I, 16
    - durability I, 16
- Interchangeable arc lamps II, 22
- Intrinsic brightness II, 40
- Irregular reflection II, 41

K

- Knob and tube wiring I, 14

L

- Light, distribution of II, 12
- Light standards II, 59
  - amyl acetate lamp II, 61
  - carcel lamp II, 61
  - English candle II, 59
  - German candle II, 61
  - pentane lamp II, 61
- Lighting of
  - public halls, offices, etc II, 48
  - residences II, 42
  - shops II, 73
  - street II, 51
- Lightning arresters I, 78

Part Page
Line capacity I, 43
Linework
  overhead I, 68
  underground I, 79
Lummer-Brodhun photometer II, 63

M

Magneto I, 37
Manholes I, 87
Matthew's integrating photometer II, 67
McCreary shade II, 57
Mean spherical candle-power II, 13
Mercury vapor lamp II, 32
  diagram of II, 33
  dimensions of II, 32
Moulding, wires run in I, 9
Multiple or parallel systems of power distribution II, 38
Multiple-series and series-multiple systems of power distribution II, 38
Multiple-wire systems of power distribution II, 39
Mutual induction I, 42

N

Nernst lamp II, 25
  advantages of II, 29
  ballast resistance II, 26
  cut-out II, 26
  distribution curve for II, 30
  glowers II, 25
  heater tubes II, 25
  single-glower lamp II, 29
  six-glower lamps II, 27

O

Open arcs for D. C. systems II, 20
Osmium lamps II, 31
Outlet-boxes I, 63
Overhead linework I, 68
  corners I, 75
  cross-arms I, 75
  insulators I, 77
  lamps on poles I, 79
  lightning arresters I, 78
  pins I, 77
  pole guying I, 72
  poles for I, 70
  poles, placing of I, 69
  service mains I, 77

P

Pentane lamp II, 61

Part Page

- Photometers... II, 62
  - Lummer-Brodhun... II, 63
  - Matthew's integrating... II, 67
  - Weber... II, 66
- Photometry... II, 59
  - arc light... II, 71
  - incandescent lamp... II, 68
  - light standards... II, 59
    - amyl acetate lamp... II, 61
    - carcel lamp... II, 61
    - English candle... II, 59
    - German candle... II, 61
    - pentane lamp... II, 61
  - working standards... II, 61
- Pole guying... I, 72
- Poles for overhead linework... I, 70
- Polyphase circuits... I, 53
- Porcelain insulators... I, 18
- Power distribution for electric lamps... II, 34
  - multiple or parallel systems... II, 38
  - multiple-series and series-multiple systems... II, 38
  - multiple-wire systems... II, 39
  - series system... II, 34

R

- Rating of arc lamps... II, 22
- Reflection of light... II, 41
- Regular reflection... II, 41
- Residence lighting... II, 42
  - illumination... II, 42
  - lamps, arrangement of... II, 44
  - lamps, type of... II, 42
- Rigid conduit... I, 1
- Rod feed lamps... II, 18

S

- Screw-joint fibre conduit... I, 84
- Series lamps... II, 17
- Series system of power distribution for electric lamps... II, 34
- Shades and reflectors... II, 55
  - frosted globes... II, 56
  - holophane globes... II, 57
  - McCreary shade... II, 57
  - opal enclosing globes... II, 58
- Shop lighting... II,73-82
  - artificial... II, 77
  - Cooper-Hewitt light... II, 82
  - distribution of sunlight... II, 75
  - electric... II, 79

Part Page

- Shop lighting
  - Welsbach burner II, 78
- Shunt lamps II, 16
- Six-glower lamp II, 27
- Skin effect in A. C. circuits I, 42
- Sleeve-joint fibre conduit I, 84
- Special lamps II, 23
  - Bremer arc II, 31
  - mercury vapor II, 32
  - Nernst II, 25
  - osmium II, 31
- Spherical intensity, measurement of II, 70
- Steel armored cable I, 6
- Street lighting II, 51
- Sunlight, distribution of II, 75

T

- Tables
  - arc lamps, lighting data for II, 50
  - armored conductors, types, dimensions, etc I, 8
  - conductors, sizes of in fibrous conduit I, 15
  - conduit, single wire in I, 2
  - conduit, two wires in one I, 3
  - conduit, three wires in one I, 3
  - Cooper-Hewitt lamps, lighting data for II, 51
  - drop in A. C. lines, data for calculating I, 47
  - enclosed arcs on constant-potential circuits II, 22
  - fibre conduit I, 85
  - flexible steel conduit, Greenfield I, 5
  - globe combinations for street lighting, efficiency of different II, 58
  - intrinsic brightness of several light sources II, 40
  - lights, distance between II, 54
  - Meridian lamps, illuminating data for II, 46
  - mouldings, sizes of, required for various sizes of conductors I, 12
  - pole data I, 71
  - residence lighting data II, 48
  - rigid, enameled conduit, size, dimensions, etc I, 2
  - shades and reflectors II, 56
  - skin effect, data for calculating I, 42
  - vitrified conduit, standard I, 81
  - voltage, effects of change in II, 10
  - white light, amount of, reflected from different materials II, 41
- Testing electric wiring equipment I, 36
  - magneto method I, 37
  - portable galvanometer method I, 37
  - voltmeter method I, 37
- Three-wire system of electric wiring, details of I, 22
- Two-wire system of electric wiring I, 20

U

- Underground linework I, 79

	Part	Page
Underground linework		
conduit, laying of	I,	82
drawing in the cables	I,	86
fibre conduit	I,	83
iron pipe	I,	80
manholes	I,	87
vitrified tile conduit	I,	80
Unit of illumination	II,	40
V		
Vector diagram	I,	44
Vitrified tile conduit	I,	80
Voltmeter	I,	37
W		
Weber photometer	II,	66
Welsbach burner	II,	78
Wiring, electric bell	I,	89
Wiring, methods of	I,	1
concealed knob and tube wiring	I,	13
wires run concealed in conduits	I,	1
armored cable	I,	6
inflexible metal conduits	I,	4
in rigid conduits	I,	1
wires run exposed on insulators	I,	16
wires run in moulding	I,	9
Wiring, systems of	I,	20
Wiring an office building	I,	54
basement, plan of	I,	55
character of load	I,	55
electric current supply	I,	54
feeders and mains	I,	55
first floor plan	I,	58
interconnection system	I,	58
second floor plan	I,	58
switchboard	I,	55
upper floor plan	I,	58
Wiring installation, method of planning	I,	29
feeders and mains	I,	36
outlets, location of	I,	30
testing	I,	36
wiring, method of	I,	29
wiring, systems of	I,	30